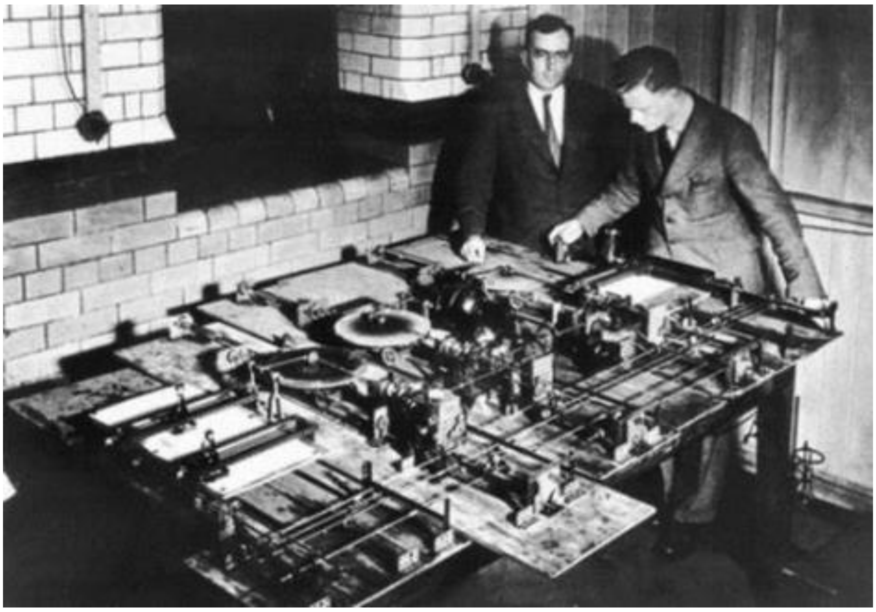
Object Identity: Deconstructing the 'Hartree Differential Analyser' and Reconstructing a Meccano Analogue Computer



Presented to the School of History at the University of Kent,
in fulfilment of the requirements of the degree of
Doctor of Philosophy

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It wasn’t work, it was play!

- Arthur Porter

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Abstract

In 1934, a child's construction toy – Meccano – was used to build the first differential analyser in the UK. Initially intended as a proof-of-concept model, the original Meccano differential analyser proved so successful at resolving equations that many subsequent Meccano and non-Meccano analogue computers were built in the UK. These machines were used before, during, and after the Second World War as research instruments and teaching devices. Despite this, the part of the original Meccano differential analyser that has sat in the Science Museum since 1949 has been used to tell a Whiggish history of computers that focuses on digital machines at the expense of analogue mechanisms. While historians of computing today define their work in opposition to this linear-progressive account of computing, this approach featured prominently in academic literature until the turn of the millennium.

This thesis explores Hartree and Porter's original Meccano differential analyser as an analogue computer, using it as a case study to explore the complex relationships between Meccano, play, science, and engineering. In doing so, it considers the object as an assemblage of its Meccano materiality, its instrumentality as an analogue computer, and its career as a collected object in the Science Museum. It deconstructs these different elements of the assemblage and explores how they are part of wider, external assemblages that have their own public histories. The thesis considers the changing materiality of Meccano as an object from 1901 to the present day, analysing marketing materials, the *Meccano Magazine*, and the voices of the Meccanomen to challenge the conventional, synchronic history of the toy as an unchanged engineering tool. It uses the Meccanomen's popular publications together with archival sources and interviews to historicise the 'alternative' version of the Meccanomen's movement, making it possible to see how individuals attached a variety of personalised meanings to their Meccano hobby.

It also explores the object’s instrumentality as an analogue computer, beginning with a detailed ‘nuts and bolts’ comparison of how the original Meccano differential analyser worked with how it was presented in academic and popular publications in 1934. It then brings together the stories and applications of other differential analysers constructed in Britain during this period, to provide further case studies about the role of these computers during the Second World War, and how they have been displayed in museums. The thesis then draws on these analyses by telling the story of the ‘Trainbox’ object that was collected by the Science Museum in 1949. The ‘Trainbox’ was comprised of parts of the original Meccano differential analyser that Hartree used to teach the principles of differential equations and integration after the Second World War. Through exploring how the public history and voices of the object have been changed in different exhibits in the museum, this thesis demonstrates the complex relationship between different parts of object’s assemblage in a variety of contexts over time. The final part of the thesis builds on these deconstructed elements by reconstructing the original object as the Kent machine, a historical reproduction designed to recover elements of the tacit knowledge used to build it in 1934. It finishes by exploring how these new understandings of Meccano and analogue computers were used to co-curate a new public history for this curious object, using the ‘shared authority’ of myself, the Meccanomen, and audiences we engaged with the Kent machine.

Introduction: Hartree, Computers, and Meccano

When asked to picture a computer, most of us think of our smartphones, laptops, and satnavs. Each of these is an example of a digital computer that models problems and represents different outputs using discrete information, which is expressed in binary code (0 and 1). We are less likely to think about analogue computers when asked this question, despite also being surrounded by them in the form of clocks, slide rules, and to an extent, our brains.[1] In contrast to digital computers, analogue computers model problems using continuously changing quantities of physical attributes and express them symbolically. This was the computing method used in the first UK differential analyser – an analogue computer that mechanically solves equations via integration – built by Professor Douglas Hartree and his research student Arthur Porter at the University of Manchester in 1934. Their machine modelled equations by changing the physical rotation speeds of two input lead-screws attached to a wheel-and-disc mechanism. The varying rotation speed (X) and relative position (Y) of the horizontal glass wheel physically represented the input variables of equations, which were integrated (XY) before being drawn graphically on an output table (see figure 1).

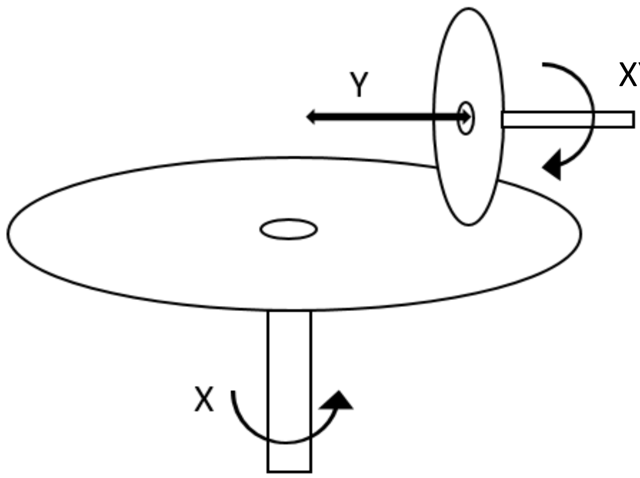

Figure 1: An image of a glass wheel-and-disc integrating unit, demonstrating how it integrates two different input functions of an equation (X and Y) into an output integral (XY). (Image drawn by author).

[1] Analogue clocks represent time as the movement of two hands, while slide rules represent numbers as varying lengths. Our brains are understood as composites of analogue and digital, in J. J. Moore et al., 'Dynamics of Cortical Dendritic Membrane Potential and Spikes in Freely Behaving Rats,' *Science*, Vol. 355, eaaj1497 (2017).

Figure 2: Douglas Hartree during his time at the University of Manchester. He created the first differential analyser from Meccano with Arthur Porter in 1934, to mechanise the processes of integration he had previously hand-computed with his father. Hartree was born 27 March 1897 and died 12 February 1958. (© IEEE Computer Society).

Douglas Hartree's decision to adopt this new analogue computing technology was an outcome of his career in computational mathematics over the previous two decades. He had attended St. John's College, Cambridge for his undergraduate studies, before moving to support the work of A. V. Hill at the Ministry of Munitions during the First World War. Douglas joined his father, William Hartree (an engineering lecturer at the University of Cambridge), as part of 'Hill's Brigands,' a group of mathematicians who resolved differential equations via the hand-computed method, using pens, paper, and a slide rule. The hand-computed method was the primary means used to create firing tables for anti-aircraft guns during the First World War, despite the existence of desk calculating machines.[2] The reason for this was that the

[2] The most popular brand of these desk calculating machines was Brunsviga, which developed mechanical, pin-wheel calculators in the 19th century. These machines allowed people to calculate four main arithmetic functions (addition, subtraction, multiplication, and division). For more on these machines, refer to, L. J. Comrie, 'On the Application of the Brunsviga-Dupla Calculating Machine to Double Summation with Finite Differences,' *Monthly Notices of the Royal Astronomical Society*, Vol. 88 (5), (March 1928), pp. 447-459.

desk calculating machines were cumbersome to operate, relatively slow, and did not significantly reduce error, which meant they could not be used to resolve equations quicker or much more accurately than the hand-computing process.[3] Hartree's experiences of the challenges associated with both these desk calculating machines and the hand-computed method during the First World War led him to seek out new methods to resolve differential equations during the rest of his career.

Hartree returned to Cambridge to complete his undergraduate studies in 1922 after publishing parts of his wartime work on 'Ballistics Calculations' in a 1920 issue of *Nature*.[4] He then went on to complete his Ph.D. in atomic wave functions in 1926 before developing his 'Self-Consistent Field Theory' in 1928.[5] Hartree's 'Self-Consistent Field' method allowed him to simplify the mathematics derived from Schrödinger's equation, turning them into differential equations that could be calculated by hand.[6] His work led to the development of the Hartree-Fock method, in which Hartree used to calculate atomic wave functions and make a series of advances in the field of quantum mechanics.[7] However, as the mathematics involved in this work became more complicated, Hartree found that the methods available to him were no longer sufficient to support his work. For equations that required advanced calculus, the hand-computing method was slow and laborious, while existing desk calculating

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[3] Hartree's greatest contribution during the war was his innovation of using time instead of elevation angle as an independent variable in ballistics equations. For more information on his work during this period, refer to W. Van der Kloot, 'Mirrors and Smoke: A. V. Hill, his Brigands, and the Science of Anti-Aircraft Gunnery in World War I,' *Notes & Records of The Royal Society*, Vol. 65, (2011), pp. 393-410

[4] D. R. Hartree, 'Ballistic Calculations,' *Nature*, Vol. 106, (1920), pp. 152–154.

[5] Hartree's 1926 Ph.D. focused on Bohr's atomic theory research into the atomic wave functions of hydrogen atoms. Atomic wave function equations are used to describe the probability density of particles. For more on these topics, refer to M. A. Slawinski, *Seismic Waves and Rays in Elastic Media* (Elsevier, 2003); and L. A. Ostrovsky and A. I. Potapov, *Modulated Waves: Theory and Application* (Johns Hopkins University Press, 2003).

[6] For more on the Self-Consistent Field Theory and the Hartree-Fock method, refer to C. Froese Fischer, 'General Hartree-Fock Program,' *Computer Physics Communication*, Vol. 43 (3), (1987), pp. 355–365.

[7] D. R. Hartree, and W. Hartree, 'Self-Consistent Field, with exchange for Nitrogen and Sodium,' *Proceedings of the Royal Society,* Vol. 193 (1034), (London, 1934), pp. 299-304.

machines could only complete four arithmetic functions (addition, subtraction, multiplication, and division).

In an attempt to find a new computational method to support his work, Hartree (by this point, the Beyer Chair of Applied Mathematics at the University of Manchester) visited the Massachusetts Institute of Technology (MIT) in 1933 to see a new type of analogue computer that Vannevar Bush had invented in 1931 (see figure 3).

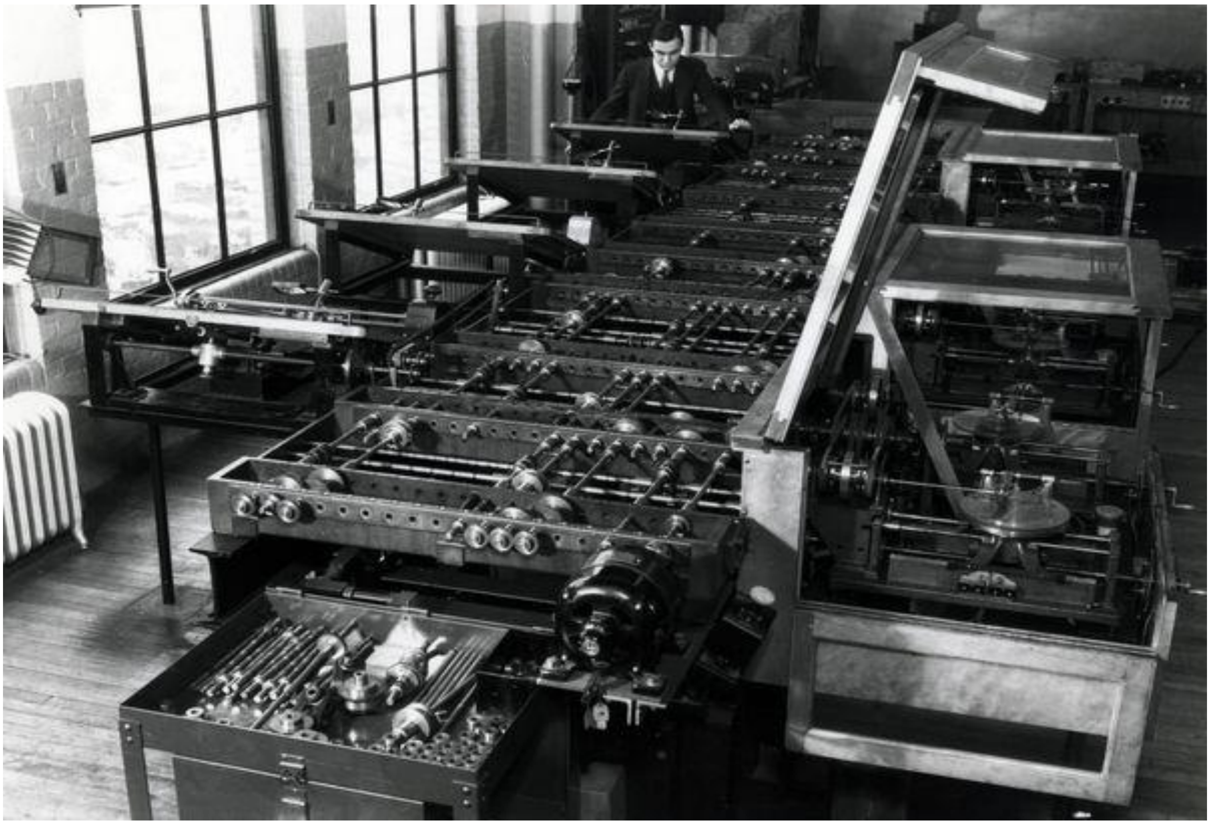

Figure 3: An image of Vannevar Bush's MIT Analyser in 1931. Hartree and Porter based the design of their differential analyser on Bush's machine. (©The MIT Museum and Historical Collections).

Bush's MIT differential analyser allowed him to mechanise the arithmetic processes of addition, subtraction, multiplication, and division. However, unlike previous desk calculating machines, the MIT differential analyser could also mechanise the processes of calculus and numerically solve differential equations for which there was no formal solution. The mechanical method of the analyser dramatically increased the speed and accuracy of equation calculations when compared to previous methods and machines.[8] It was after his second visit to Bush that Hartree, having observed the various gearing components, shafts, and wheels of the MIT differential analyser, commented that 'it looked as if someone had been enjoying himself with an extra-large Meccano set.'[9]

Despite making this apparently flippant remark, Hartree worked with Arthur Porter (a graduate student) to develop their own version of Bush's MIT analyser when he returned to the UK. Although they originally intended it to only be a proof-of-concept model of Bush's machine, they used it to resolve equations relating to theoretical physics and mathematics (see figure 4).

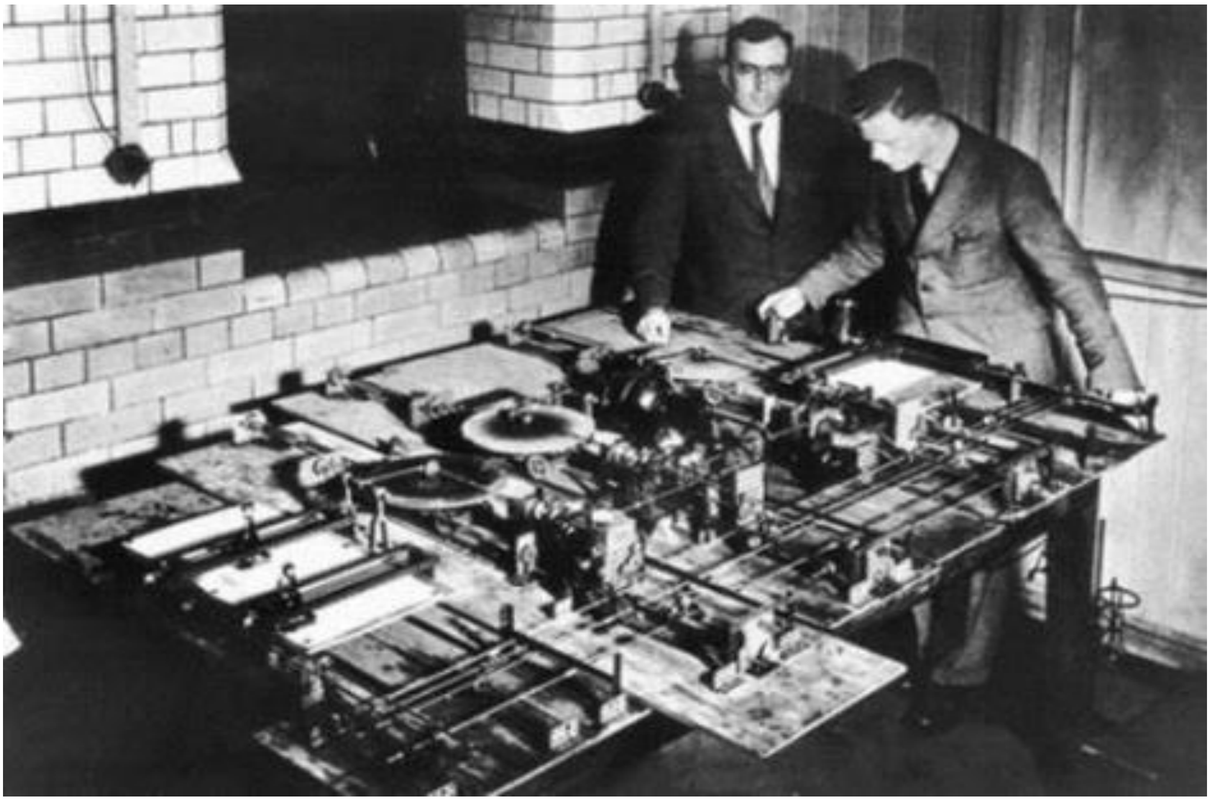

Figure 4: An image of the original Meccano differential analyser built by Douglas Hartree (L) and Arthur Porter (R) in 1934. (© Science and Industry Museum Informal Collection).

[8] V. Bush, 'The Differential Analyser: A New Machine for Solving Differential Equations,' *Journal of the Franklin Institute*, Vol. 212, (1931), pp. 447-488; and J. Crank, *Differential Analysers* (Longmans, 1947), pp. 1-15.
[9] D. R. Hartree, 'The Mechanical Integration of Differential Equations,' *The Mathematical Gazette*, Vol. 22 (251), (1938), p. 349.

While Porter used it to resolve atomic wave functions for his MSc dissertation in 1934, and later for his Ph.D. thesis in 1936, Hartree used the analyser to develop and test his work on the Hartree-Fock method, as part of his work in quantum mechanics.[10] The success of these applications led Hartree and Porter to assert that their differential analyser had 'exceeded their expectations' and provided the basis on which they successfully applied for funding to build a larger, bespoke version.[11] After receiving £6,000 from the University of Manchester in 1935, Hartree and Porter worked with Metropolitan Vickers to build a newer, larger analyser, the 'Manchester machine,' which they used alongside their original differential analyser for a series of industrial and academic applications from 1935.[12]

The success of the original differential analyser and the Manchester machine inspired the creation of many other differential analysers in the UK during this period, including at the University of Cambridge, Queen's University, Belfast, and the Institute of Actuaries. Except for Hartree and Porter's original differential analyser, these analogue computers were used

[10] Science and Industry Museum Archives, SIM 510.8, A. Porter, 'The Construction of a Model Mechanical Device for the Solution of Differential Equations, with Applications to the Determination of Atomic Wave Functions,' (MSc. Thesis, University of Manchester, 1934); Science Museum Archives, Wroughton, MS473/1, A. Porter, 'The Differential Analyser and Some Applications,' (Ph.D. Thesis, University of Manchester, 1936); and C. Froese Fischer, 'General Hartree-Fock Program,' *Computer Physics Communication*, Vol. 43 (3), (1987), pp. 355–365.

[11] D. R. Hartree, and A. Porter, 'The Construction and Operation of a Model Differential Analyser,' *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, Vol. 79, (1934), p. 54.

[12] This funding is discussed in D. R. Hartree, 'The Differential Analyser,' *Nature*, Vol. 136, (1935), pp. 940-943 and in a Science and Industry Museum Archives, MSO237/21, Letter from Metropolitan Vickers to University of Manchester, 1935. A selection of articles on the applications of the two differential analysers before the Second World War include: D. R. Hartree, 'On An Equation occurring in Falkner and Skan's Approximate Treatment of the Equations of the Boundary Layer,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 33, (1937), pp. 223-239; D. R. Hartree, and B. Swirles, 'The Effect of Configuration Interaction on the Low Terms of the Spectra of Oxygen,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 33, (1937), pp. 240-249; D. R. Hartree, and J. R. Womersley, 'A Method for the Numerical or Mechanical Solution of certain types of Partial-Differential Equations,' *Proceedings of the Royal Society A*, (1937), pp. 353-366; D. R. Hartree, and A. Porter, 'The Application of the Differential Analyser to Transients on a Distortionless Transmission Line,' *Institute of Electrical Engineering Journal*, Vol. 83, (1938), pp. 648-656; D. R. Hartree, and W. Hartree, 'Wave Functions for Negative Ions of Sodium and Potassium,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 34, (1938), pp. 550-558; D. R. Hartree, 'The Mechanical Integration of Differential Equations,' *The Mathematical Gazette*, Vol. 22 (251), (1938), pp. 342-364; and D. R. Hartree, W. Hartree, and B. Swirles, 'Self-Consistent Field, including Exchange and Superposition of Configurations with some results for Oxygen,' *Philosophical Transactions of the Royal Society*, Vol. 238 (790), (1939), pp. 229-247.

during the Second World War, with applications including equations relating to ballistics tables, radar technology, magnetron technology, and Tube Alloys (the British/Canadian equivalent of the US Manhattan Project).[13] In 1947, Hartree cannibalised pieces from the original differential analyser and used them to create a reduced version of an analyser, without input and output tables. He programmed it with the 'tractive force equation' in relation to locomotives to teach audiences the main principles of mechanical integration.[14] His decision to use this equation led the object to be named Hartree's 'Trainbox,' which he toured around Britain from 1947-1949 (see figure 5).

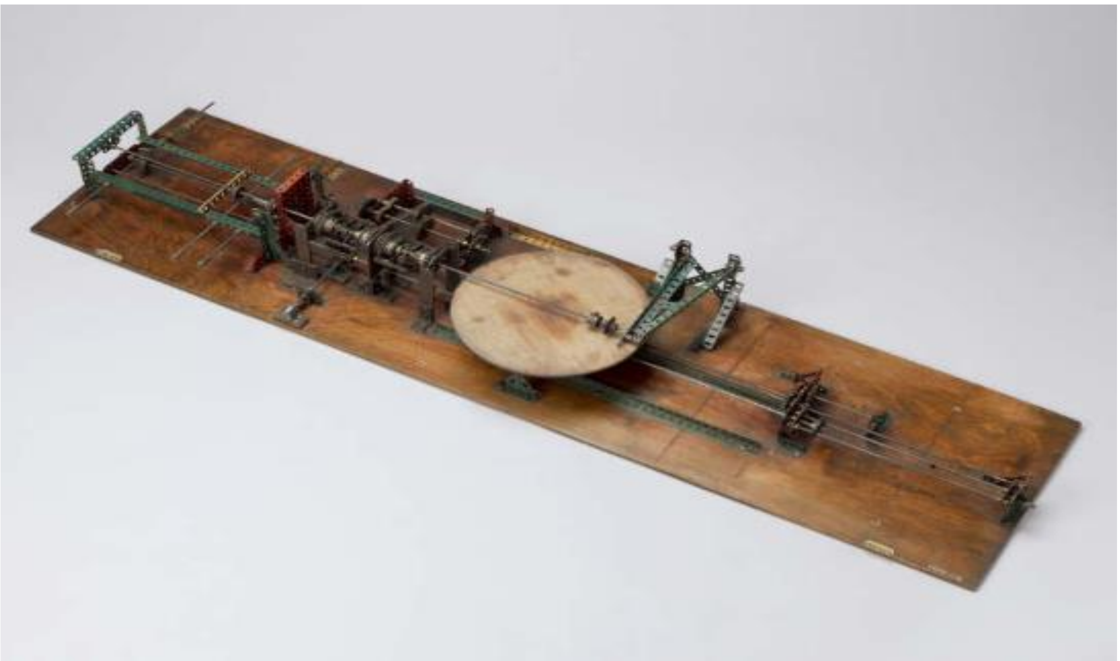

Figure 5: The Trainbox model rebuilt by Douglas Hartree in 1947 using parts taken from his original 1934 differential analyser. This object currently sits in the Web Exhibit of the *Information Age* gallery. (Image reproduced from Science Museum Archives, Sc. M. 1949-134).

[13] These analysers are discussed in the following articles: J. E. Lennard-Jones, M. V. Wilkes, and J. B. Bratt, 'The Design of a Small Differential Analyser,' *Proceedings of the Cambridge Philosophical Society*, Vol. 35, (1939), pp. 485-493; H. S. W. Massey, J. Wylie, R. A. Buckingham, and R. Sullivan, 'A Small-scale Differential Analyser: Its Construction and Operation,' *Proceedings of the Royal Irish Academy Section A*, Vol. 45, (1938), pp. 1–21; and R. E. Beard, 'The Construction of a Small-scale Differential Analyser and its Application to the Calculation of Actuarial Functions,' *Journal of the Institute of Actuaries*, Vol. 71 (2), (March 1942), pp. 193-227. The information about these applications and uses comes from a number of sources, which are explored in Chapter Three. However, two of the main primary sources used were: UK National Archives, DEFE 15/751-C20779, Memorandum No. 27/44, W. J. Cairns, J. Crank, and E. C. Lloyd, 'Some Improvements in the Construction of a Small-scale Differential Analyser and a Review of Recent Applications,' *Armament Research Department Theoretical Research*, (1944); and D. R. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

[14] When applied to locomotives, the tractive force equation is used to calculate the amount that a train can push or pull. For more on this, refer to S. Iwnicki, *Handbook of Railway Vehicle Dynamics* (CRC Press, 2006).

In 1949, Henry Calvert (Curator of Mathematics and Calculating Machines at the Science Museum) contacted Hartree, seeking to collect the Trainbox for a display of analogue computers. It was swiftly accessioned by the Science Museum, where it continues to be displayed today in the Web Exhibit of the *Information Age* gallery. The Trainbox is exhibited today as, 'A working model of a differential analyser, 1934,' despite consisting of a single integrating unit with no input or output table.[15] The stories the object is used to tell are those of Hartree and Porter's original differential analyser (as both a proof-of-concept and cutting-edge mathematical machine) and Hartree's Trainbox (as both a teaching object and museum exhibit). The changing identity and voices of the Trainbox make it, and by extension, the original differential analyser, curious case studies for historians of science and computing, especially for those interested in understanding how objects change in museums. However, what makes these two objects even more curious, compelling, and in need of further analysis, is that both were built from the child's construction toy, Meccano (see figure 6).

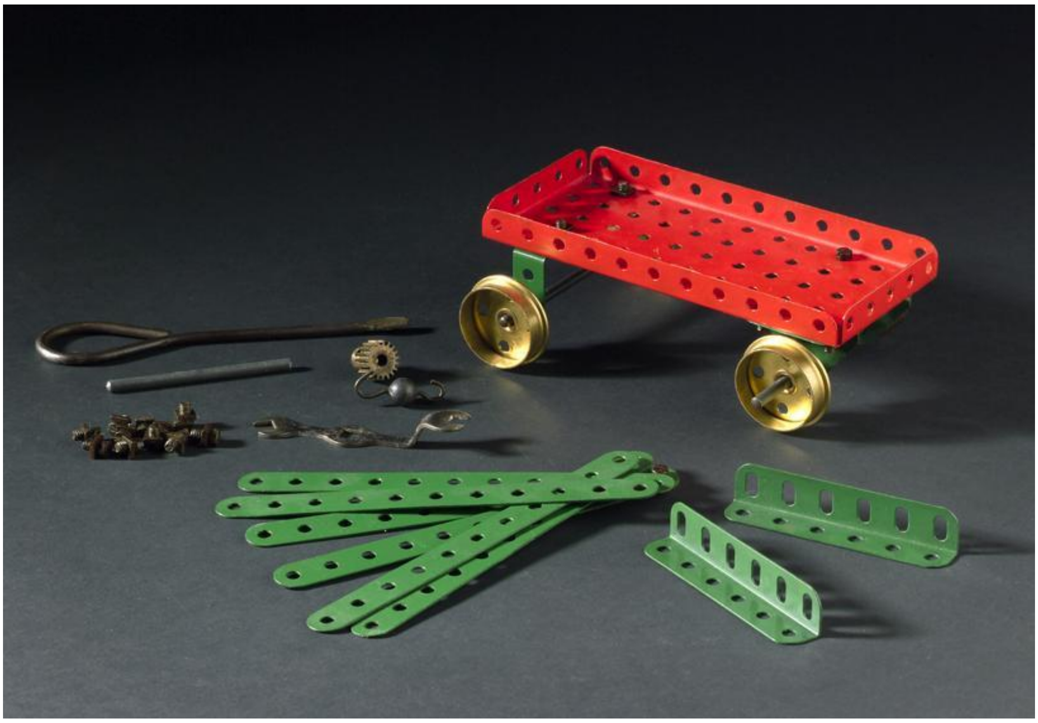

Figure 6: An image of the child's construction toy Meccano. The colour-scheme of the pieces in the image denote the same as those used by Douglas Hartree and Arthur Porter in 1934. (© The Board of Trustees of the Science Museum).

[15] Label from *Information Age* gallery exhibit, (Information collected by author, 11th November 2016).

1. Hornby and Meccano

Figure 7: Frank Hornby, the inventor of Meccano and the *Meccano Magazine*. He developed other Hornby products, including Dinky Toys and the Dublo Model Railway system. Hornby was born on 15 May 1863 and died on 21 September 1936. (© Public Domain).

Frank Hornby invented ‘Mechanics Made Easy’ in 1901 as a construction toy that children could use to build models of cranes, railways, and windmills.[16] Renamed ‘Meccano’ in 1907, the physical pieces of the toy were comprised of metal strips and girders that had an odd number of equally spaced holes along their length. The purpose of the odd number of holes was to create a middle point on each of these pieces, to which users could connect the gears, pulleys, and wheels, using ‘nuts and bolts’ that also featured in these sets. Hornby’s original patent for Mechanics Made Easy contained images of an early model crane and a railway track, indicating the types of models that he envisaged users would build with these early sets (see figure 8).

[16] Hornby initially developed his construction system in 1898, but did not complete and patent it until 1901.

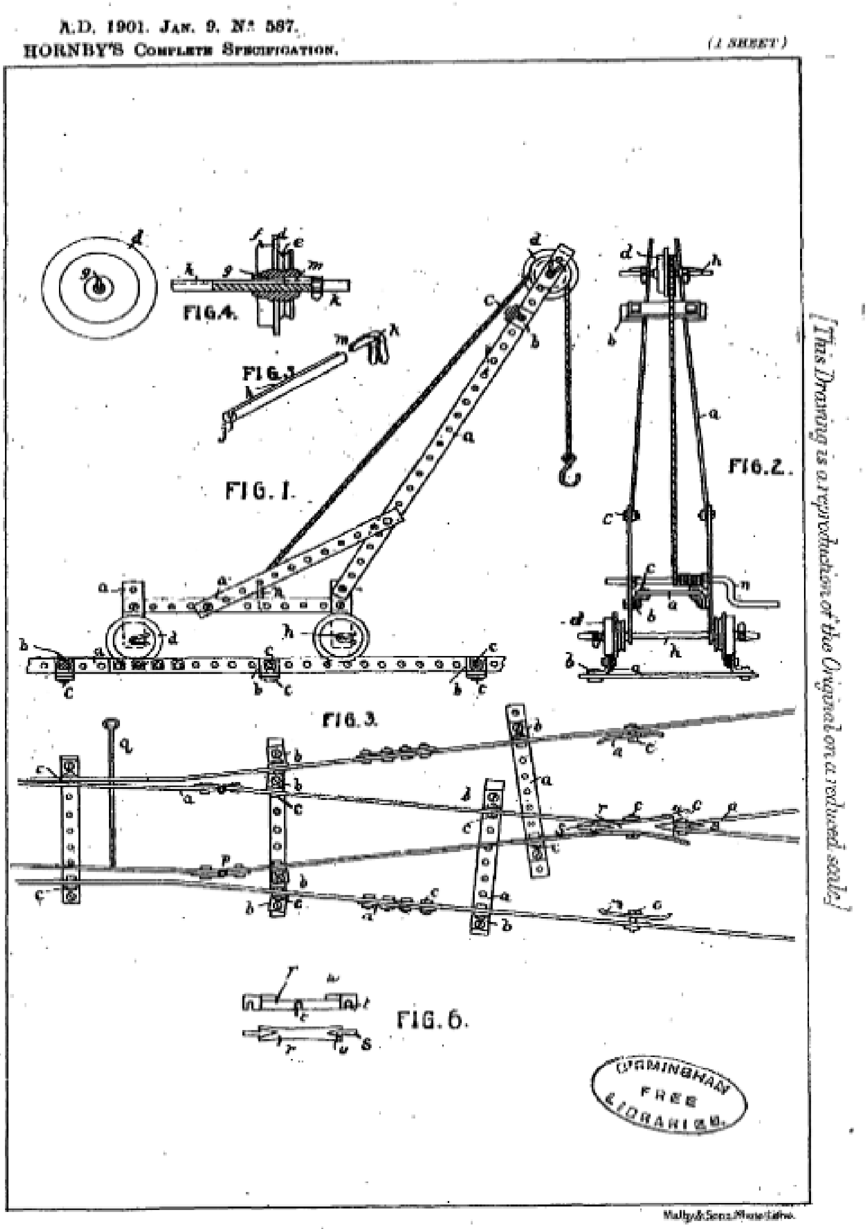

Figure 8: An image of Hornby's original 'Mechanics Made Easy' pieces from his 1901 patent for the toy. It demonstrates how the pieces were put together in six separate figures. (Image reproduced from Patent No. 587-1901, F. Hornby, 'Improvements in Toy or Educational Devices for Children and Young People,' (9 January, 1901), p. 4).

Hornby asserted that he had invented Meccano in response to a '...long-felt want [for the] means whereby the interest in mechanical construction from an elementary point of view, is enhanced in addition to providing an interesting means of mechanical education.'[17] He believed that the 'standardised pieces' of Meccano were 'engineering objects in miniature'

[17] Patent No. 587-1901, F. Hornby, 'Improvements in Toy or Educational Devices for Children and Young People,' (9 January, 1901), pp. 1-4.

and helped to provide ‘children of ingenuity’ with a mechanical education.[18] In the first decade after Hornby invented Meccano as an educational toy for children, he continued to develop the marketing on Meccano sets and manuals, increasingly featuring young boys and marginalising girls (see figure 9).

Figure 9: An image of the 1910 Meccano manual, featuring two boys playing with it to build a model windmill. This style was adopted for much of the 1910s, 1920s, and early 1930s.
(Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-10).

Meccano continued to grow in popularity before the First World War, in part thanks to its growing status as the ‘boy’s toy’ that provided a mechanical education. However, Meccano was not a homogenous system, but was developed by the introduction of *The Hornby System of Mechanical Demonstration*. While this new system contained pieces of Meccano, it was not advertised as a toy, but was recommended to schools as a cheap, flexible method to construct scientific and engineering apparatuses in the classroom.[19] Hornby set up a factory

[18] E. Hawks, ‘The Lighter Side of Meccano,’ *Meccano Magazine*, Vol. VII, No. 3, (March, 1922), p. 1.
[19] The Hornby System of Mechanical Demonstration Manual, 1908-13, https://www.meccanoindex.co.uk/Mmanuals/Theme/Manuals/HSMD.pdf [accessed 21 March 2016].

at Binns Road in Liverpool in 1914 to support this continued growth of Meccano, which remained in use for over six decades.

Hornby also developed and edited the *Meccano Magazine* during the First World War to support the growth of Meccano. The magazine was a monthly free-publication, which he used to publicise new pieces, sets, and models to users (officially dubbed as ‘Meccano boys’ in the first issue) until 1921 when he left his role as editor to focus on developing other Hornby products.[20] He was succeeded by Ellison Hawks, who continued to develop the *Meccano Magazine*, increasing its readership to 80,000 changing Meccano into an international brand that signified real-world science and engineering.[21] It was during Hawks’ editorship that Douglas Hartree and Arthur Porter used Meccano to build their differential analyser in 1934. When Hawks left in 1935, W. H. McCormick took over as editor and began to change the *Meccano Magazine*, decreasing the international content in favour of British engineering articles that contained an increasing emphasis on nationalistic messages in the lead up to the Second World War.

The conventional public histories of Meccano situate it as a synecdoche of British engineering, often implying both a correlation and causation between the popularity of Meccano before the Second World War and the perceived ‘golden age’ of British engineering. A synecdoche is a figure of speech where a part of something is used to represent the whole; an example of this is using the word ‘wheels’ to refer to a vehicle. This thesis engages with the stories, identities, and users of Meccano from throughout the twentieth century to demonstrate that Meccano has been incorrectly used as a synecdoche for British engineering

[20] This thesis uses the original numbering for the different issues of the *Meccano Magazine*. The early volumes used Roman numerals until March 1964 when they were changed to numerical digits.
[21] P. Bowler, ‘*Meccano Magazine*: Boys’ Toy and the Popularisation of Science in Early Twentieth-Century Britain,’ *British Journal for the History of Science: Themes*, Vol. 3, (2018), p. 131.

in public histories, and perspectives composed by different users and historians. It establishes that these historical perspectives tend to overlook the pre-war changes to Meccano and the fact that its popularity began to decline *after* the Second World War, as new cheaper alternatives became available. It seeks to demonstrate that it was a failure to adapt and update the Meccano brand that led to a series of buyouts and bad decisions in the 1960s and 1970s, and which resulted in the development of the fan-led Meccanomen version of the hobby, and the eventual closure of the Binns Road factory and British Meccano operations in 1981. The primary production of Meccano products was subsequently transferred to Meccano France, which continues to develop new sets of Meccano today. While these contemporary sets use different materials, represent different concepts, and are aimed at boys and girls, the physical pieces of Meccano are still essentially the same as the original patent design described by Frank Hornby in 1901.

2. Toys, Play, and Science

Wider historical scholarship on the relationship between toys, play, science, and engineering in the UK is limited. The majority of studies have been in the fields of psychology or sociology and focused on child development, learning styles, and familial relationships.[22] Johan Huizinga's *Homo Ludens: A Study of the Play-Element in Culture* (1944) was one of the first attempts to analyse play as a cultural phenomenon. His book states that for historians to effectively tackle the function of toys and play in culture, they needed to start their research 'where biology and psychology leave off' and accept that playing with toys is irrational and the 'direct opposite of seriousness.'[23] The trend since his book has been that play and toys have been treated as subjects of importance, with many studies that focus on the historical role of toys within culture, although the majority are case studies from outside the UK.[24] In the few examples that are based in the UK, the majority have not analysed toys as cultural objects in relation to science. Instead, British historians have focused on the economic and business history of toys, using them as analogies for the wider boom and bust of the British economy in the twentieth century.

An example of this British literature is historian Kenneth Brown, who wrote three books on the British toy business in the twentieth century, including *Factory of Dreams: A History of Meccano Ltd, 1901-1979* (2007). Brown's research provides useful background

[22] Some examples include: E. P. Johnsen, 'Searching for the Social and Cognitive outcomes of Children's Play: A Selective Second Look,' *Play & Culture, Vol. 4* (3), (1991), pp. 201-213; J. H. Goldstein, *Toys, Play, and Child Development* (Cambridge, 1994); D. Fleming, *Powerplay: Toys as Popular Culture* (Manchester, 1996); B. Sutton-Smith, *Toys as Culture* (New York, 1996); I. Opie, and P. Opie, *Children's Games with Things* (Oxford University Press, 1997); and M. Warner, *Only Make-Believe: Ways of Playing* (Compton Verney, 2005).

[23] J. Huizinga, *Homo Ludens: A Study of the Play-Element in Culture* (Routledge & Kegan Paul, 1944), pp. 11-16.

[24] These examples from outside the UK include: M. Formanek-Brunell, *Made to Play House: Dolls and the Commercialization of American Girlhood, 1830–1930* (Baltimore, 1998); D. Hamlin, *Work and Play: The Production and Consumption of Toys in Germany* (Ann Arbor, 2007); B. Ganaway, *Toys, Consumption, and Middle-Class Childhood in Imperial Germany, 1871–1918* (Oxford, 2009); and B. P. L. Hutchinson, 'Making (Anti) Modern Childhood: Producing and Consuming Toys in late Victorian Canada,' *Scientia Canadensis: Canadian Journal of the History of Science: Technology and Medicine,* Vol. 36 (1), (2013), pp. 79–110.

context on why ‘mainstream’ Meccano began to decline in popularity after the Second World War. However, his publications and analysis predominantly focus on the business history of the company, overlooking both the role of the toy as a cultural object and the creation of the amateur Meccanomen movement in 1965. This thesis brings together these business and economic histories of Meccano to explore how it changed as a cultural and scientific object before and after the Second World War. The main approaches used to achieve this include an analysis of the changing signifiers of the *Meccano Magazine* and a series of systematic interviews conducted with the Meccanomen.

The Meccanomen movement was created by a group of Meccano boys who organised themselves against changes made to – what this thesis describes as – ‘mainstream’ Meccano products after the Second World War. In response, they created their own independent publications and groups to allow them to engage with Meccano differently and hark back to the values and themes that they believed were part of the ‘golden age’ of the toy. It also explores how they took to creating their own Meccano pieces, as part of what this thesis will call the ‘alternative’ version of Meccano. This movement has continued since the closure of the ‘mainstream’ British Meccano operations in 1981, with over 600 members around the UK today who are members of their groups and the International Society of Meccanomen. The members of this movement and their independent publications have not been included in previous analyses of Meccano.

This thesis also incorporates the public histories of the toy written by these Meccano enthusiasts to better understand Meccano in the context of the emergent Meccanomen movement. It establishes that this literature tends to focus on cataloguing the specifications of historical Meccano products and models, rather than how Meccano has culturally changed over time.[25] In contrast to these catalogues and technical manuals, Meccanoman and popular historian, Roger Marriott's *Meccano* (2016) approaches the toy as a cultural and scientific object, providing detailed descriptions of the formation and early days of the Meccanomen movement as part of the more general story of Meccano. He tells his story of Meccano using a vast supply of visual sources, which includes historical publications, instruction manuals, and sets. However, Marriott's predominant focus is on telling the story of the Meccanomen movement after 1965, which he tells in a Whiggish manner that presents its popularity (as a successor to 'mainstream' Meccano) as a guarantee from the outset.[26]

Another example of how users can change the meaning of scientific toys in a cultural context is in Aaron Alcorn's US case study, 'Flying into Modernity: Model Airplanes, Consumer Culture, and the Making of Modern Boyhood in the Early Twentieth Century' (2009). Alcorn presents the hobby of aeromodelling as part of an 'ecology of practice,' a term he uses to encapsulate the variety of social practices associated with the hobby, including clubs, magazines, and books. He assesses how the boys who pursued this hobby challenged the technological vision of becoming 'modern' that was attached to aeromodelling by their parents, and created their own 'alternative' versions of the hobby in the process.[27] While Alcorn's research explores the development of 'alternative' versions, he does not analyse how the meanings attached to these versions develop and change over time. Nevertheless, this thesis draws on his research by establishing how successive generations of Meccanomen have

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[25] P. Ralph, *The Products of Binns Road: A General Survey* (New Cavendish Books, 1977); G. Wright, *The Meccano Super Models: 002* (New Cavendish Books, 1978); and B. Love, and J. Gamble, *The Meccano System and the Special Purpose Meccano Sets, 1901-1979* (New Cavendish Books, 1986).

[26] R. Marriott, *Meccano* (Shire Publications, 2016).

[27] A. L. Alcorn, 'Flying into Modernity: Model Airplanes, Consumer Culture, and the Making of Modern Boyhood in the Early Twentieth Century,' *History and Technology*, Vol. 25 (2), (2009), pp. 115-146.

developed and changed the meanings attached to their 'alternative' version since 1965, and how these contrast to the conventional public history of Meccano.

Alongside Alcorn's US example is Ruth Oldenziel's 'Boys and Their Toys: The Fisher Body Craftsman's Guild, 1930-1968, and the Making of a Male Technical Domain' (1997). Oldenziel discusses how the Fisher Body Craftsman's Guild used a variety of techniques, including model-making contests to make boys and men into technophile designers, while changing the role of girls and women into more passive builders of an expanding consumer society. Their advertisements in the early-1930s strongly suggested that play was not light-hearted for boys and that building Fisher models would lead them to engineering careers and scholarships. Her work demonstrates how, in a US context, boys were pushed into the technical aspect of society, while girls were steered away from it.[28] This thesis builds on Oldenziel's work in a nuanced way, by establishing that in the UK, Meccano was used to push boys to be technical producers through the creation of models, but that it was also used to push them in a much wider variety of directions during the prewar period.

Building on Oldenziel's work, there are two academic examples that have focused on British toys in a scientific-cultural context. The first is Gerard Turner's 'Scientific Toys' (1987), which tells the story of toys as part of a history of education. Turner uses the Wimshurst machine as his example of a scaled-down version of industrial machines. He explains that these scientific recreations were 'intended for young boys' to allow them to explore static electricity in miniature in the 1900s. His conclusion calls for historians of science to address the lack of scholarship of specific objects and toys in Britain through cultural studies of 'Homo

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[28] R. Oldenziel, 'Boys and Their Toys: The Fisher Body Craftsman's Guild, 1930-1968, and the Making of a Male Technical Domain' (1997) *Technology and Culture*, Vol. 38 (1), (1997), pp. 60-96.

Ludens' in the context of science and engineering studies.[29] His analysis concludes at the start of the twentieth century, just before Meccano was patented and sold for the first time. This thesis answers Turner's call by exploring how Meccano – and the scientific and engineering skills that it was believed to teach users – changed in British culture during the twentieth and twenty-first centuries.

The second example of scholarship on British science toys in a cultural context is Melanie Keene's Construments research. Construments are a construction toy similar to Meccano that provided users with 'reduced versions' of optical equipment that they could use to make a variety of working instruments, including 'Magnifiers, Kaleidoscopes, and Low Power Cameras.' Keene describes how Construments were invented in response to the educational debates in Britain during the interwar period, alluding to the fact that their success – as the 'Science Made Easy' brand – was built on the success of Meccano (originally Mechanics Made Easy). She also asserts that 'actual, as well as ideological links connected Construments and Meccano,' as Ellison Hawks (the *Meccano Magazine* editor from 1921-1935) was also an early director of the Construments brand.[30]

However, in contrast to Keene's research, which analyses Construments as an unchanging cultural object of play during a specific period of twentieth-century Britain, Meccano is explored as a scientific and engineering toy that continually developed both before and after the Second World War. This thesis builds on these previous academic and popular publications about toys as cultural and economic objects by exploring Meccano as

[29] G. Turner, 'Presidential Address: Scientific Toys,' *British Journal for the History of Science*, Vol. 20, (1987), pp. 377–398.
[30] M. Keene, '"Every Boy & Girl a Scientist:" Instruments for Children in Interwar Britain,' *Isis*, Vol. 98 (2), (2007), pp. 269-270.

part of an internal assemblage of the original Meccano differential analyser, and as part of a series of external assemblages with its users, British industry, and culture.

When I started this thesis in 2015, Keene's publication was the closest exemplar for my method in researching Meccano. However, since working on this thesis, there have been two publications that have focused primarily on Meccano and the *Meccano Magazine* as scientific-cultural objects. Although briefly discussed in *Science for All: The Popularisation of Science in Early Twentieth-Century Britain* (2009), Peter Bowler researched the development of the *Meccano Magazine* during the interwar period more thoroughly in his 2018 article, '*Meccano Magazine*: Boys' Toy and the Popularisation of Science in Early Twentieth-Century Britain.' In it, he asserts that the *Meccano Magazine* increased in popularity during the interwar period because it indirectly cornered a large proportion of the adult market for popular science by adopting 'a very similar content and presentation' to its adult rivals, *Armchair Science*, *Conquest*, and *Discovery*.[31] He describes how the success of the *Meccano Magazine* was because it was a 'juvenile equivalent' to these magazines, which he believed gave readers a clear vision of science and engineering in relation to Meccano.[32] Bowler's argument that the *Meccano Magazine* provided a single vision of science and engineering to readers is based on the idea that because the physical pieces of Meccano did not change during the interwar period, neither did their meaning. This thesis dispute this by extending on Bowler's analysis of the *Meccano Magazine* and exploring the publication to demonstrate that it was an object that was used and changed throughout the twentieth century to represent different versions of science and engineering in Britain. Despite not directly

[31] P. Bowler, *Science for All: The Popularisation of Science in Early Twentieth-Century Britain* (University of Chicago Press, 2009), and P. Bowler, '*Meccano Magazine*: Boys' Toy and the Popularisation of Science in Early Twentieth-Century Britain' *British Journal for the History of Science: Themes*, Vol. 3, (2018), pp. 144-146.
[32] Ibid., pp. 134-140.

developing on Bowler's perspective of how children understand and engage with science separately from adults, it establishes how Meccano and the *Meccano Magazine* represented science and engineering in different ways.

The second publication on Meccano as a scientific-cultural object from this period was written by Ruth Wainman. She uses '"Engineering for Boys": Meccano and the Shaping of a Technical Vision of Boyhood in Twentieth-Century Britain,' (2017) to tell the story of Meccano before the Second World War, exploring how it 'shaped a technical vision of boyhood' during the interwar period by introducing boys to engineering. She asserts that Hornby's original vision for Meccano as an engineering object was based on the principles of Samuel Smiles' self-help literature from the nineteenth century and was similar to the Boy Scout movement, formed in 1908. Through an analysis of the early Meccano manuals and sets, she asserts that Hornby shaped his toy to provide the training and skills that he believed would allow boys to participate in technical and engineering professions. The main theme in her research is that the editors of the *Meccano Magazine* before the Second World War (Ellison Hawks and W. H. McCormick) maintained Hornby's original technical vision in their versions of Meccano and the *Meccano Magazine*. Wainman uses letters sent into the *Meccano Magazine* to support this argument that Meccano provided a stable 'technical vision of boyhood…[by] appealing to adolescent boys with aspirations towards their own social betterment through education and work.' She concludes that Hornby 'shaped a technical vision of boyhood' during the interwar period by using Meccano to introduce boys to the principles of engineering and self-help from Samuel Smiles' work.[33]

[33] R. Wainman, '"Engineering for Boys": Meccano and the Shaping of a Technical Vision of Boyhood in Twentieth-Century Britain,' *The Journal of the Social History Society*, Vol. 14 (3), (2017), pp. 381-396.

However, the limitation of Wainman's analysis is that she posits that the 'technical vision' was uniform for all users, similar to Bowler's assumption that the unchanged physical pieces of Meccano during this period provided a 'clear vision' of science and engineering. This thesis demonstrates that instead of Wainman's belief that Meccano provided a uniform 'technical vision of boyhood' before the Second World War, there were four distinct versions of Meccano cultivated during Hornby's, and later Hawks' and McCormick's tenures as editor of the *Meccano Magazine*. It establishes that while she uses two letters written by Meccano boys from the 1917 issue of the *Meccano Magazine* to support her argument of a 'technical vision,' her analysis overlooks a third letter that featured in the same issue of the magazine. Written by R. H. Cobbold, 'Meccano as a Toy' describes Meccano as a playful and educational toy, which contrasts to the two letters Wainman uses to support her 'technical vision' of Meccano as an engineering tool.[34]

In contrast to these two publications, Chapter One performs a semiotic analysis of the *Meccano Magazine* establish that more than one version of Meccano existed during the interwar period. It demonstrates that instead of providing a single 'technical vision of boyhood,' Hornby cultivated Meccano to be used as both an educational toy for Meccano boys and a training tool for would-be engineers. It highlights how Hawks turned Meccano into an aspirational emblem of fan-participation in international science and engineering that was used to raise the aspirations of users, and how McCormick reshaped Meccano into the synecdoche of British of engineering that has informed previous historical analyses in the years after 1935.

[34] R. H. Cobbold, 'Meccano as a Toy,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 2.

Another interesting aspect of Wainman's research into Meccano is her use of oral histories from the British Library's 'An Oral History of British Science' (OHBS) archive.[35] Wainman describes how Meccano played an important role in shaping the careers for many of the scientists and engineers interviewed. She concludes that the respondents articulated their professional identities in a similar manner to how the *Meccano Magazine* presented the 'inventive' boy.[36] I drew on these same interviews and conducted my own with members of the International Society of Meccanomen, which allowed me the chance to go more in-depth on the issues of individual identity, group identity, and enthusiast characteristics. I worked with the Meccanomen to encourage them to co-curate what this thesis calls 'participant historiographies' on the 'golden ages' of Meccano, British engineering, and popular decline. This participatory approach (that combines principles from oral history and public history) demonstrates that they compose perspectives that do not fit with the conventional public history of Meccano and the International Society of Meccanomen. Instead, their voices highlight that their personal experiences with Meccano have a larger impact on their self-identity than their governing organisation, and that despite giving answers that challenge the conventional public history, they do not experience 'discomposure.'

[35] British Library, 'An Oral History of British Science,' https://sounds.bl.uk/Oral-history/Science [accessed 2 October 2016].

[36] R. Wainman, '"Engineering for Boys": Meccano and the Shaping of a Technical Vision of Boyhood in Twentieth-Century Britain,' *The Journal of the Social History Society*, Vol. 14 (3), (2017), pp. 389-392.

3. The ‘Hartree Differential Analyser’ as an Analogue Computer

While one half of this thesis focuses on the original Meccano differential analyser as a Meccano model, the other half focuses on it as an analogue computer that is part of the history of computing. James Small asserted in his 2001 publication that the history of computing is plagued by what he calls the ‘analogue gap.’ His argument in *The Analogue Alternative, The Electronic Analogue Computer in Britain and the USA, 1930-1975* was that when analogue computers do feature in literature, they are presented as linearly-related precursors to digital computers, rather than as significant co-actors in the history of computing.[37] Despite a concerted by historians since Small’s work to move away from these types of analyses in an attempt to decrease the ‘analogue gap,’ elements remain in literature and museum exhibits of these computers today. The thesis aims to provide case studies that support the work of other historians in closing the ‘analogue gap.’ Chapter Three does this by examining the British analogue machines as computers for the first time and exploring how their uses changed during and after the Second World War.

An example the ‘analogue gap’ features in Jon Agar’s *Turing and the Universal Machine: The Making of the Modern Computer* (2001), which reduces and separates Hartree’s machines and work with both analogue and digital computers to just two sentences:

> Douglas Hartree was the authority on numerical methods of solving mathematical problems. [He] constructed an analogue calculator, the Differential Analyser, in the

[37] J. Small, *The Analogue Alternative, The Electronic Analogue Computer in Britain and the USA, 1930-1975* (Routledge, 2013), p. 5.

> 1930s… [As] an expert on machine calculation, [Hartree] was advising the ENIAC team and ensured that the links with the British were maintained.[38]

In contrast to this perspective, Chapter Three will establish that Hartree's writings from this period highlight how his experiences using the analogue Manchester machine informed the way he developed the digital ENIAC (Electronic Numerical Integrator and Computer) in 1946, establishing that he represented a nexus between these two computing methods.[39] In contrast to Hartree's publications, Agar's phrasing disconnects Hartree's expertise with both analogue and digital computers and also conflates Hartree and Porter's Meccano differential analyser from 1934 with the subsequent and separate Manchester machine they built with Metropolitan Vickers in 1935. This type of conflation was common throughout the history of computing literature and resulted in the attributes of both the original Meccano differential analyser and the Manchester machine being discussed and described as if they were the same object.

Another example of this challenge of identity that is a result of the 'analogue gap' features in Mindell's *Between Human and Machine* (2002). In it, Mindell discusses Hartree and Porter's work with analogue computers, before asserting that 'their machine is now on display in the Museum of Science in London [sic].'[40] What is not clear is which of the three objects he is alluding to with this statement (the original Meccano differential analyser, the Manchester machine, or the reconstructed Trainbox object). It is unlikely that he is discussing the Manchester machine as the machine was split in half in 1973, with the parts going to both

[38] J. Agar, *Turing and the Universal Machine: The Making of the Modern Computer* (Icon Books, 2001), p. 116.
[39] D. R. Hartree, *Calculating Machines: Recent and Prospective Developments, and their Impact on Mathematical Physics* (Cambridge, 1947), pp. 44-51.
[40] D. A. Mindell, *Between Human and Machine: Feedback, Control, and Computing before Cybernetics* (Johns Hopkins University Press, 2002), p. 158.

the Science Museum and SIM. Therefore, his use of the term 'their machine' implies that it was the original Meccano differential analyser built in 1934 by Hartree and Porter. However, the problem with his use of the phrase 'their machine' is that the Science Museum did not collect the original machine built by Hartree and Porter, but the rebuilt Trainbox object that Hartree created alone in 1947. While the Trainbox was built from pieces of the original, it had a completely different instrumentality, being used to teach the principles of mechanical integration to audiences around the country, rather than resolve differential equations.

Walter Isaacson's *The Innovators* (2014) contains an example of this, despite discussing the development of both analogue and digital computing methods before the Second World War. His analysis of analogue computers focuses on Vannevar Bush's MIT differential analyser, which he describes as 'particularly useful in churning out artillery fire tables – and in training and inspiring the next generation of computer pioneers.' However, he concludes that Bush's machine was 'not destined to be a major advance in computing history because it is an analogue device,' and that 'it turned out to be the last gasp for analogue computing…for many decades.'[41] While Isaacson does reference the British analogue computers during this period, he also conflates the two machines that Hartree and Porter constructed in 1934 and 1935. His 'last gasp' analysis underestimates the contribution to mathematics and computing that these analogue machines made before, during, and after the Second World War.

Elements of the 'analogue gap' also appear Charlotte Froese Fischer's book, *Douglas Rayner Hartree: His Life in Science and Computing* (2003), which provides a biographical account of Hartree's life, based on her experiences as his final Ph.D. student. The challenge

[41] W. Isaacson, *The Innovators* (Simon and Schuster, 2014), pp. 36-38: 72-78.

of Froese Fischer's structure is that she separates his career with different computational engineering methods into three distinct periods. The first discusses his hand-computed work during and after the First World War, his creation of the Self-Consistent Field Theory, and the Hartree-Fock method of calculating atomic wave functions. The second introduces the original Meccano differential analyser, the Manchester machine, and Hartree's role at the Ministry of Supply during the Second World War. The third section begins with a chapter titled 'Dawn of the Computer Era,' which focuses on Hartree's post-war role in the advancement of early digital computing technology, specifically his time in America with the ENIAC, and in Cambridge with the EDSAC (Electronic Delay Storage Automatic Computer).[42] These types of analysis tend to result in the name 'Hartree Differential Analyser' being used interchangeably for the original Meccano analyser, the Manchester machine, and the Trainbox objects, conflating them when they are written about and displayed in museums.[43]

This conflation of identity is evident when one googles the term 'Hartree Differential Analyser' today. The first 'Hartree Differential Analyser' webpage suggested is not about the original Meccano differential analyser, but for the Manchester machine that is on display at the Science and Industry Museum (SIM) in the city of its creation.[44] The misnamed Manchester machine highlights the continued challenges of identity caused by the 'analogue gap' when objects are collected in museums. Throughout the rest of this thesis, the name 'Hartree Differential Analyser' is not used. Instead, as part of deconstructing the assemblage

[42] The EDSAC is the Electronic Delay Storage Automatic Calculator, which features in C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific, 2003), Ch. 13, pp. 145-160.
[43] B. Collier, and J. MacLachlan, *Charles Babbage and the Engines of Perfection* (Oxford University Press, 1998); J. Essinger, *Jacquard's Web: How the Hand-Loom Led to the Birth of the Information Age* (Oxford University Press, 2004); D. Ince, *The Computer: A Very Short Introduction* (Oxford University Press, 2011); and S. Lavington (ed.), *Alan Turing and his Contemporaries: Building the World's First Computers* (British Informatics Society Limited, 2012).
[44] 'Hartree Differential Analyser' http://www.cs.man.ac.uk/~lindsec/hartree.html [accessed 28 September 2015].

of identities of the original Meccano differential analyser, it uses the most appropriate name in the context within which different parts of the object are being discussed. These names include the original Meccano differential analyser, the original differential analyser, the Meccano analyser, and when discussing it in the Science Museum, the 'Trainbox.'[45]

The complex identities, interactions, and conflations of these analogue computers become further apparent when one observes how the Science Museum has used the Trainbox object. Despite missing an input and output table, which are needed to programme and use the analyser to resolve equations, the museum has described it as 'a Meccano differential analyser' and 'a working differential analyser,' in various exhibits since 1949. Chapter Four of this thesis explores how the 'analogue gap' in the history of computing impacted how the Science Museum has changed the identity of the Trainbox. It uses the analogy of ventriloquism to explore the different voices that the Trainbox has been made to speak with by curators, in order to give it new identities that have allowed it to tell the different stories of computing the museum has needed since 1949.

[45] The thesis does not use the name 'Hartree Differential Analyser' to refer to the Manchester machine either. When each differential analyser discussed, its original name is used. Chapter Seven briefly returns the name 'Hartree Differential Analyser' as it was the name I used when advertising public demonstrations of the Kent machine.

4. Museums, Object Identities, and Assemblages

The movement of the Trainbox object into the Science Museum in 1949 provides an entirely new way to approach how its identity changed and developed. The role of museums in the collection and development of objects is a rich area of material culture scholarship that can be split into different groups. The first group this section focuses on are those that attempt to understand how objects change through analysing the internal development and management of museums through their policies and procedures.[46] Simon Knell, Suzanne MacLeod, and Sheila Watson state in *Museum Revolutions: How Museums Change and Are Changed* (2007) that the traditional view of museums is that they 'were established to capture and concretise progress – to gather up things as they have become known and valued, and keep them unchanged.'[47] They challenge this view by asserting that museums are as much about people as objects, and that staff in museums constantly 'foreground aspects of the past in order to construct a narrative' for the objects in their collection.[48] Chapter Four borrows elements from this object-focused museum literature and combines them with both cultural studies and the internal policies of the Science Museum to understand how the identity of the Trainbox has been changed on a hands-on basis.

Chapter Two explores how the precision of the Meccano pieces used to build the machine, as well as the presence of 'accuracy bias' and human-induced errors, demonstrating that these had a significant bearing on the actual accuracy rate and usefulness of the object in a research context. It builds on Andrew Warwick's book chapter 'The Laboratory of Theory, or: What's Exact about the Exact Sciences' (1995), in which discusses the 'general invisibility'

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[46] D. Dean, *Museum Exhibition: Theory and Practice* (Routledge, 1994); and K. Moore (ed.), *Museum Management* (Routledge, 1994).
[47] S. J. Knell, S. MacLeod, and S. Watson (eds.), *Museum Revolutions: How Museums Change and are Changed* (Routledge, 2007), p. xix
[48] Ibid., p. xxii.

of the 'workaday problems' associated with using objects. He asserts that computational procedures are a crucial part of the interface between mathematical theory and experiment, and that they must be included in any historical discussion of accuracy or precision.[49] This thesis builds on his work by analysing the 'nuts and bolts' instrumentality of the original Meccano differential analyser, to better understand the 'workaday problems' of the object, and to provide a contrast to how it has been presented in other literature. This exploration highlights that the accuracy rate attributed to the machine in the Meccano Magazine (that led it to be called a 'Mechanical Marvel') overlooked the processes that made the machine work, which changed how it was used, understood, and displayed in the Science Museum.[50]

A central theme of the cultural studies of objects in museums is that meanings are attached to specific cultural narratives that are present when they are collected.[51] Elsner and Cardinal assert that the way objects are classified in museums 'mirrors the collective humanity's thoughts and perceptions.'[52] Eilean Hooper-Greenhill's *Museums and the Shaping of Knowledge* (1992) supports this idea of how objects are changed in museums with her assertion that there is '…no essential identity for museums' but that such 'identities as are constituted are subject to constant change as the play of dominations shifts and new relations of advantage and disadvantage emerge.'[53] Meanwhile, Jeanne Cannizzo's perspective is that 'the stories we tell ourselves about ourselves are institutionalised and materialised in our

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[49] A. Warwick, 'The Laboratory of Theory or What's Exact about the Exact Sciences?,' in M. N. Wise (ed.), The Values of Precision (Princeton University Press, 1995), p. 313.
[50] E. Hawks, and D. R. Hartree, 'Machine Solves Mathematical Problems: A Wonderful Meccano Mechanism,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 442.
[51] These include: P. Vergo (ed.), *The New Museology* (Reaktion Books, 1989); J. H. Falk, and L. D. Dierking, *The Museum Experience* (Whalesback Books, 1992); S. M. Pearce, *Museum Objects and Collections: A Cultural Study* (Leicester University Press, 1992); S. H. Dudley, *Museum Materialities: Objects, Engagements, Interpretations* (Routledge, 2010); and S. H. Dudley (ed.), *Museum Objects: Experiencing the Properties of Things* (Routledge, 2012).
[52] J. Elsner, and R. Cardinal (eds.), *The Cultures of Collecting* (Reaktion Books, 1994).
[53] E. Hooper-Greenhill, *Museums and the Shaping of Knowledge* (Routledge, 1992), p. 191.

museums.'[54] Similar to this, Gaynor Kavanagh states that 'the museum makes public the histories it produces through the medium of exhibition…based on ideas derived from consideration of available sources. It is a version of the past, not the past itself.'[55]

This thesis also utilises aspects of studies on object identity from outside of the museum context to better understand complex identities of the original Meccano differential analyser as a Meccano model and as an analogue computer. Igor Kopytoff asserts that objects can change as a result of their use and that they have their own biographies in his chapter in Arjun Appadurai's *The Social Life of Things: Commodities in Cultural Perspective* (1988). According to Kopytoff, object biographies help to elevate an object's role in culture; biographies reveal the politics of objects and make them active parts of a culture's own biography and development.[56] Kopytoff's ethnographic approach to the subject-object relationship is an attempt to demonstrate the different systems of meaning of an object from the subject's perspective, across diverse cultural groups.[57] Reflecting on this ethnographic approach, Karin Dannehl's chapter 'Object Biographies' in Karen Harvey's *History and Material Culture: A Student's Guide to Approaching Alternative Sources* (2009) critiques Kopytoff and Appadurai's object biographies for omitting contexts in which objects can be possessions, status symbols, products, or some form of all of these.[58] Dannehl's research highlights one of the fundamental challenges faced in writing about the original Meccano differential analyser as a historical and cultural object. This challenge is that the analyser has

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[54] J. Cannizzo, 'Exhibiting Cultures: "Into the Heart of Africa,"' *Visual Anthropology Review*, Vol. 7 (1), (1991), p. 151.
[55] G. Kavanagh, *History Curatorship* (Leicester University Press, 1990), p. 127.
[56] I. Kopytoff, 'The Cultural Biography of Things: Commoditisation as Process,' in., A. Appadurai, *The Social Life of Things: Commodities in Cultural Perspective* (Cambridge University Press, 1988), pp. 64-95.
[57] This ethnographic approach is used extensively in literature from this period. A review of the topics in Appadurai's book shows a broad range of contexts, including the Eastern Solomon Islands, prehistoric Europe, and the origins of Swadeshi in early-modern Indian society.
[58] K. Dannehl, 'Object Biographies,' in K. Harvey (ed.), *History and Material Culture: A Student's Guide to Approaching Alternative Sources* (Routledge, 2009), pp.123-138, quote on p. 125.

distinct object biographies – as a Meccano model, an analogue computer, and a museum object – each of which has different contexts of use, both culturally and historically throughout time.

Bruno Latour expresses concern with Kopytoff's predilection with object biographies in *We Have Never Been Modern* (1993). He asserts that object biographies focus too much on the cultural agency of the subject at the expense of what he calls a more interactive 'natures-cultures' relationship. Instead of recommending object biographies, Latour suggests approaching and understanding objects as part of an 'ontology of things.'[59] However, Daniel Miller's *Material Cultures: Why Some Things Matter* (1998) contrasts to Latour's ontology of things. Miller frames objects as part of a larger process of culture and asks 'how objects matter to people,' concluding that they need to be understood as a realistic extension of humanity. By objectifying culture in this way, Miller asserts that objects are embedded in social processes and as a result, represent meaning beyond simply their form, function, and instrumentality.[60] Christopher Pinney's chapter 'Automonsters' in Peter Wollen and Joe Kerr's *Autopia: Cars and Culture* (2002) develops on Miller's approach by arguing that objects must be elevated further in their relationship with humans, and that material culture should be considered as a zone in which humans and objects are 'folded into each other.'[61]

In contrast to this material culture literature, Christopher Tilley's *The Materiality of the Stone: Explorations in Landscape Phenomenology* (2004) argues for a new phenomenology of objects. His perspective is that the different properties of an object – material and conceptual – should not be seen as independent of each other, but rather as

[59] B. Latour, *We Have Never Been Modern*, trans. Catherine Porter (Harvard University Press, 1993), p. 7.
[60] D. Miller (ed.), *Material Cultures: Why Some Things Matter* (UCL Press, 1998), p. 12.
[61] C. Pinney, 'Automonsters,' in P. Wollen, and J. Kerr (eds.), *Autopia: Cars and Culture* (Reaktion Books, 2002), p. 228.

part of a whole that is interpreted by the subject.[62] In his later works on object phenomenology, Tilley cites the work of Amiria Henare, Martin Holbraad and Sari Wastell, who, in *Thinking Through Things: Theorising Artefacts Ethnographically* (2007), place an emphasis on the subject's interpretation of the real world of the object, rather than how it is theoretically understood as part of an ontology of things.[63] This thesis borrows aspects from these phenomenological approaches, by analysing each of the object identities of the original Meccano differential analyser individually, and as part of a larger assemblage with external networks, such as the Meccanomen movement and the development of the history of computing literature.

This assemblage-thinking defines the way that this thesis approaches the objects *and* their audiences as things that have interacted and changed each other over time. Martin Müller's article, 'Assemblages and Actor-Networks: Rethinking Socio-Material Power, Politics and Space' (2015), provides a blueprint for this type of assemblage-thinking alongside the actor-network theory (ANT). Müller describes assemblages as 'a mode of ordering heterogeneous entities so that they work together for a certain time.' This thesis chooses to analyse the original Meccano differential analyser as an assemblage rather than using the ANT, because its two internal identities (as a Meccano model and analogue computer) have 'intrinsic qualities outside their associations' within the larger object.[64] Linked to this approach is Samuel Alberti's *Objects and the Museum* (2005), which asserts that objects have

[62] C. Tilley, *The Materiality of Stone: Explorations in Landscape Phenomenology* (Berg, 2004), p. 12.
[63] A. Henare, M. Holbraad, and S. Wastell, *Thinking Through Things: Theorising Artefacts Ethnographically* (Routledge, 2007), p. 8.
[64] M. Müller, 'Assemblages and Actor-networks: Rethinking Socio-material Power, Politics and Space,' *Geography Compass*, Vol. 9 (1), (2015), pp. 33-35.

various attributed meanings and values that change over time. He describes how these polysemic aspects are 'inalienably connected' to different groups in museums.[65]

Therefore, this thesis combines aspects of Müller's assemblage-thinking and Alberti's analysis of museum objects to establish that the original Meccano differential analyser has distinct identities as a Meccano model, analogue computer and museum object. It also utilises aspects of Kopytoff's and Dannehl's work on object biographies and Tilley's phenomenological approach to objects alongside this assemblage-thinking approach to understand the changing contexts and identities of different parts of the original Meccano differential analyser inside and outside the museum. Rather than only approaching the object as an internal assemblage of these aspects or biographies, the thesis explores the Meccano model identity of the original differential analyser as something that is also part of an external assemblage of how Meccano has developed. It similarly analyses the analogue computer identity of the original differential analyser as something that features in and has been changed by how analogue machines have been written about in the history of computing. Put simply, this thesis analyses how the internal assemblage of the object's Meccano materiality and instrumentality as an analogue computer are also part of external assemblages that have changed over time, both inside and outside the museum.

Nicole Boivin's *Material Cultures, Material Minds* (2008) emphasises that the assemblage of objects and audiences in different contexts are important as 'the act of using an object transforms us in particular ways,' and are attached to our 'individual habits, perceptions, concepts of self, ideas of space and time, social relationships, and moral and

[65] S. J. M. M. Alberti, 'Objects and the Museum,' *Isis*, Vol. 96, (2005), p. 571.

political boundaries.'[66] Therefore, alongside exploring the impact of these changing external assemblages in an abstract, theoretical sense, I also decided to create a new assemblage by physically reproducing the original Meccano differential analyser as the 'Kent machine' (see figure 10). Chapter Seven discusses how historically reproducing the Kent machine provided an insight into the challenges of the changing internal and external assemblages of the original object that were explored and deconstructed in the preceding chapters. It also discusses how I collaborated with a variety of groups to cultivate a new public history for the object.

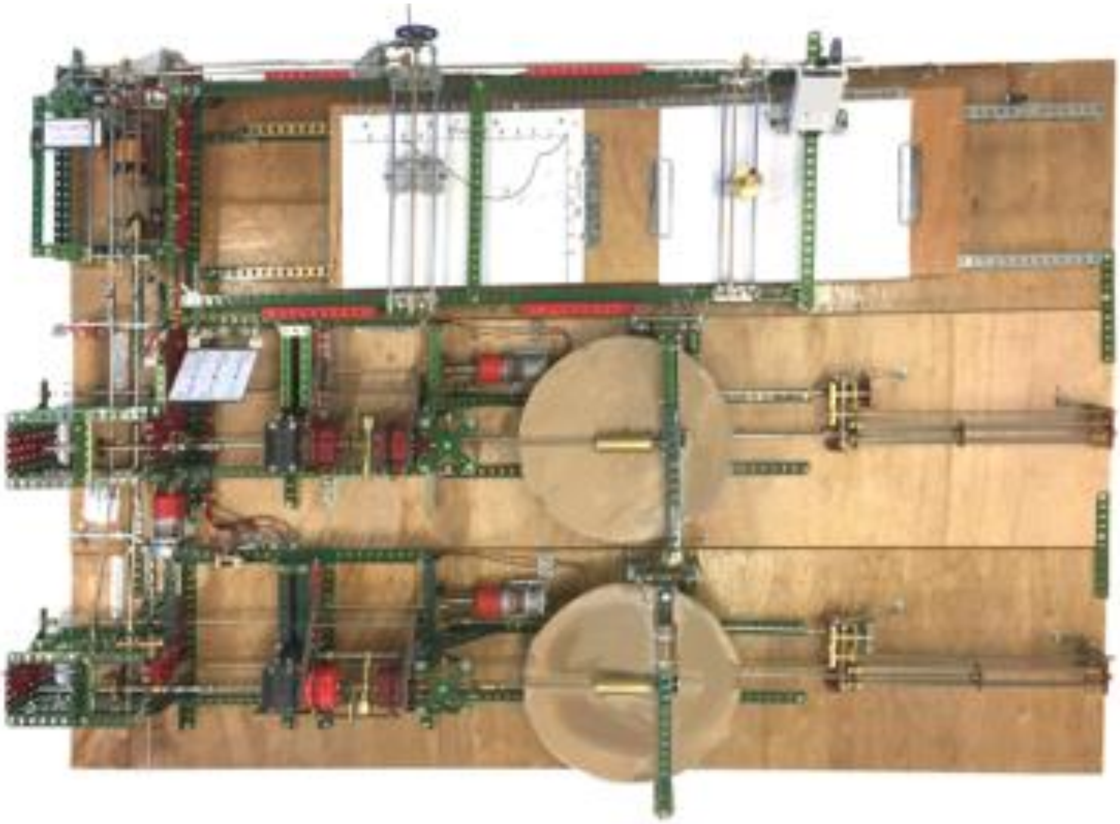

Figure 10: A birds-eye view of the Kent machine, which this thesis is built around as if it were a museum exhibit. (Image taken by author).

Due to the curious nature of the original Meccano differential analyser, another way to consider this object is whether it is a scientific instrument or not. This approach borrows from the historiography of scientific instruments, which Deborah Warner addresses in her

[66] N. Boivin, *Material Culture, Material Minds: The Impact of Things on Human Thought, Society, and Evolution* (Cambridge University Press, 2008), p. 169; and L. Winner, *Autonomous Technology: Technics-out-of-control as a Theme in Political Thought* (MIT Press, 1977), p. 9.

essay review, 'What is a scientific instrument, when did it become one, and why?' (1990). She discusses a variety of definitions of the term 'scientific instrument' that are interesting when applied to the original Meccano differential analyser, especially when it is considered that it functioned as both a Meccano model in the *Meccano Magazine*, and an analogue computer in an academic setting.[67] Liba Taub's updated version of Warner's work, 'What is a scientific instrument, now?' (2018), also discusses how the status of objects changes once they enter museums, which is discussed in Chapter Four.[68] Another interesting approach is Simon Schaffer's *Easily Cracked: Scientific Instruments in States of Disrepair* (2011) that analyses how the character of an object becomes evident when it breaks.[69] In the case of the original differential analyser, its character is inextricably linked to its material Meccano form, which was advertised as a precise engineering object in miniature.

This analysis of material culture literature has demonstrated that as it has developed, the interactions between the object and subject have been continuously redrawn, shrinking the gap between them and reducing the passivity of their relationship. Borrowing from and extending upon the works discussed above, this thesis deconstructs the original Meccano differential analyser as both a Meccano model and analogue computer. John Caputo asserts that deconstruction is a tool to be used to 'find a nutshell – a secure axiom – and crack it open.'[70] This thesis borrows from his perspective and aims to crack open the secure axioms of the conventional public history of Meccano as a synecdoche of British engineering, the history of computing, and the presentation of 'Trainbox' in the Science Museum. It does this

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[67] D. J. Warner, 'What is a scientific instrument, when did it become one, and why?' *BJHS*, Vol. 23, (1990), pp. 90-92.
[68] L. Taub, 'What is a scientific instrument, now?' *Journal of the History of Collections*, (7 December 2018), https://doi.org/10.1093/jhc/fhy045 [accessed 20 February 2019].
[69] S. Schaffer, 'Easily Cracked: Scientific Instruments in States of Disrepair,' *Isis*, Vol. 102 (4), (2011), pp. 706-717.
[70] J. D. Caputo, *Deconstruction in a Nutshell: A Conversation with Jacques Derrida* (Fordham University Press, 1997), p. 32.

by extending past the physical form and instrumentality of the object and treating it as an assemblage of its physical and conceptual pieces, that each has metaphorical, symbolic, and audience-specific identities. It then explores how I worked to include these different assemblages in the public history of the reconstructed Kent machine. Through adopting this approach, this thesis will contribute to scholarship on contemporary material culture, the history of computing, British history, oral history, and how the public engages with the history of science and scientific objects both inside and outside of the museum.

5. Public and Oral History

First manufactured in 1901, Meccano still inspires a vast network of enthusiasts today as part of the International Society of Meccanomen. With over 30 clubs in Britain and 60 around the world, the members of these amateur clubs meet quarterly and attend annual, national events. Their enthusiasm for their hobby is reflected in the vigour with which they create Meccano models and take them around the country. Some use Meccano to build model cars, some to build fairground dioramas, and some to create machines that serve as proof-of-concept models. Like many amateur enthusiasts, the Meccanomen's objects and collections of Meccano are an extension of themselves, and their identities are an assemblage of their personal experiences with their hobby and the complex history of their movement, which Russell Belk describes in the context of consumption as 'the extended self.'[71]

Susan Pearce's *On Collecting: An Investigation into Collecting in the European Tradition* (1995), describes how enthusiasts use their collections to 'construct a world' that is closer to things as they would like them to be today.[72] The members of the Meccanomen movement provide an interesting example of what Pearce is describing, as they have used their hobby to simultaneously reproduce and renovate the public history of Meccano and themselves. This thesis establishes that these changes were initially based on nostalgia in the 1960s, but later moved more towards each Meccanoman's personal experiences with Meccano. Chapter Five explores how former boys, frustrated with the changes to 'mainstream' Meccano developed their own 'alternative' version of Meccano in 1965, renaming themselves as Meccanomen in the process. It then analyses how this 'alternative'

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[71] R. W. Belk, 'Possessions and the Extended Self,' *Journal of Consumer Research*, Vol. 15 (2), (1988), p. 139.
[72] S. M. Pearce, *On Collecting: An Investigation into Collecting in the European Tradition* (Routledge, 1995), p. 175.

version developed alongside (what this thesis calls) 'mainstream' Meccano (the outfits and sets created by Meccano Ltd. since 1901), demonstrating how they changed their hobby. Chapter Six develops on this by collecting the voices of Meccanomen and exploring both their enthusiasm and critical perspectives of the conventional public history of Meccano and their movement.

Paul Thompson's *The Voice of the Past: Oral History* (1978) explains how oral history, used well, can help to transform our understanding of the past by breaking down barriers between generations, and also remove the process of *writing* history, which has its own flaws. These flaws include the preoccupation in much historical literature towards the story of the elites, or of organisations, rather than focusing on the 'everyman' of history.[73] The analysis of existing Meccano literature highlights that previous histories of Meccano have focused on structures, organisations, and industries, rather than its users. While these histories are important to tell in relation to Meccano and do feature in this thesis, the voices of Meccanomen and other enthusiasts are introduced in an attempt to understand what Elizabeth Tonkin calls their 'representation of pastness' better as well.[74]

In contrast, the critics of oral history assert that the acts of remembering and interpreting are fraught with difficulties. They assert that oral history is inherently subjective, due to the potential distortion of the interviewee's role, the influence of hindsight, and the projection back of a contemporary view or emotion, all of which are part of the personal

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[73] P. Thompson, *The Voice of the Past: Oral History* (Oxford University Press, 1978); P. Thompson, 'Britain Strikes Back: Two Hundred Years of "Oral History,"' *Oral History Association Newsletter*, Vol. 15, (1981); C. Morrisey, "The Case for Oral History," *Vermont History*, Vol. 31, (1963), pp. 145-155; J. Vansina, *Oral Tradition: A Study in Historical Methodology* (Routledge, 1965); S. Benison, 'Reflections on Oral History,' *American Archivist*, Vol. 28, (1965), pp. 71-77; and A. Seldon and J. Pappworth, *By Word of Mouth: 'Elite' Oral History* (Methuen, 1983).

[74] E. Tonkin, *Narrating Our Pasts: The Social Construction of Oral History* (Cambridge University Press, 1992), p. 2.

values and memories of those giving testimony.[75] Jeremy Black and Donald MacRaild assert that these arguments are part of the tension that exists in using oral testimonies, regarding what counts as memory and what as history.[76] While the move from the 'documentary' approach to the 'theoretical turn' in oral history has helped to address some of these concerns, there are still issues of subjectivity and intersubjectivity between the Meccanomen and myself, which are unpacked in Chapter Six.[77] This thesis argues that the perceived weaknesses of oral history are what gave the collected voices of the Meccanomen value, as what was sought was not the objective 'truth' of the history of Meccano, but a sense of their perspectives of the hobby. Therefore, Chapter Six establishes how I combined the dialogic processes of oral history with the interpretative and participatory processes of public history to interview the Meccanomen. The purpose of creating an interview scenario based on 'shared authority' was to get richer historical responses from the Meccanomen, and also to encourage them to compose 'participant historiographies' of Meccano.[78] These 'participant historiographies' are then used together with the historical reflections of the Meccanomen and voices from the OHBS Archive at the British Library to demonstrate the complex views and composure the enthusiasts experienced in relation to their hobby today.

Working with the Meccanomen to co-curate their stories of the past helped me to further deconstruct the conventional public history of Meccano as a cultural and scientific object. This experience of interviewing the Meccanomen showed me that they had a vast set

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[75] A. Seldon, and J. Pappworth, *By Word of Mouth: 'Elite' Oral History* (Methuen, 1983), p. 17; and R. Perks, *Oral History: Talking about the Past* (British Library National Sound Archive, 1992).
[76] J. Black, and D. M. MacRaild, *Studying History* (Palgrave, 2007), pp. 111-115.
[77] S. O. Rose, 'Methods/Review,' Review of *Reconstructing Women's Wartime Lives: Discourse and Subjectivity in Oral Histories of the Second World War*, by P. Summerfield (Manchester University Press, 1998), *American Historical Review*, Vol. 105 (1), (2000), pp. 172-173.
[78] C. M. Peniston-Bird, 'Oral History: The Sound of Memory,' in S. Barber, and C. M. Peniston-Bird (eds.), *History Beyond the Text: A Student's Guide to Approaching Alternative Sources* (Routledge, 2009), pp. 106-108; and M. Frisch, *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (University of New York Press, 1990), p. xxii.

of modelling skills and alternative perspectives about the conventional public history of their hobby. Hilary Geoghegan emphasises the importance of enthusiast communities' participation in creating good public history, explaining that 'co-curation, communication, and application of historical knowledge…at the heart of the idea of public history…is a commitment to the democratisation of the who, how, where, when, and what of historical work.'[79] Therefore, after interviewing the Meccanomen, I decided to collaborate with them to historically reproduce the original Meccano differential analyser as the Kent machine. Chapter Seven describes how the process of building and using the Kent machine with the Meccanomen allowed me to recover a good deal of the tacit and gestural knowledge that Hartree and Porter would have used required to build their machine in 1934, which is generally absent in existing literature and archival sources.[80] It also explains how this process helped to change my perspective and increase my understanding of analogue computers, which resulted in an increasing amount of technical expertise in the later drafts of this thesis.

Chapter Seven also provides an answer to Ludmilla Jordanova's question of 'who may speak with authority about the past, and by virtue of what qualities?'[81] It does this by analysing the various public demonstrations of the Kent machine and how they facilitated an exploration of Michael Frisch's concept of the 'bases of authority' and 'shared authority,' set out in *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (1990).[82]

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[79] H. Geoghegan, 'A New Pattern for Historical Geography: Working with Enthusiast Communities and Public History,' *Journal of Historical Geography*, Vol. 46, (2014), p. 106; and L. Jordanova, *History in Practice* (London, 2000).

[80] Examples of previous historical reproductions include: P. Heering, 'The Replication of the Torsion Balance Experiment,' *American Journal of Physics*, Vol. 60 (11), (1992), pp. 988-994; and H. Fors, L. M. Principe, and H. O. Sibum, 'From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science,' *Ambix*, Vol. 63 (2), (2016), pp. 85-97.

[81] L. Jordanova, 'Public History,' *History Today*, Vol. 50 (5), (May, 2000).

[82] For more information on the public demonstrations, refer to: 'Re-Engineering History' event (October 8-11, 2018) and 'Playful Engineering' demonstration (October 9, 2018), https://blogs.kent.ac.uk/sci-ex/2018/10/04/re-engineering-history-a-playful-demonstration/ and

It describes how I used the Kent machine to engage audiences with the public history of Meccano, STEM principles, and analogue computing as an alternative to digital to create a new public history, through a process that Hilda Kean and Paul Martin describe as 'crowdsourcing.'[83]Chapter Seven builds on Michael Frisch's conclusion that audiences need to be included in contemporary discussions of public history and the interpretive process by which historians engage with objects, by discussing how I created spaces where the audiences, the Meccanomen, and myself could engage our 'shared authority' to co-curate a new public history of Meccano.[84] It then describes how the reproductions and demonstrations of the Kent machine allowed me to create a public history for a Meccano differential analyser that reflected the deconstructed assemblage aspects of it Meccano materiality and instrumentality as an analogue computer. The co-curated public history of the Kent machine provides a direct contrast to how the Trainbox in the Science Museum.

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https://blogs.kent.ac.uk/specialcollections/2018/10/05/re-engineering-history-a-playful-demonstration/ [accessed 10 October 2018]; and M. Frisch, *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (State of University of New York Press, 1990).

[83] H. Kean, and P. Martin (eds.), *The Public History Reader* (Routledge, 2013), p. 7.

[84] M. Frisch, *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (State of University of New York Press, 1990), p. 27.

6. Primary Sources

The major area of development in this thesis compared to previous cultural analyses of objects is that it explores the identities of the original Meccano differential analyser as two separate but interconnected parts of a larger object assemblage. Previously, historians have either focused on the Meccano form of the object or its status as an analogue computer, resulting in half of the object being ignored. This introduction has demonstrated that even when historians have engaged with these halves of the story, they have done so while maintaining a 'distance' from the external assemblages of that part of the object. An example of this is Wainman's Meccano article, which uses the original differential analyser as evidence that Meccano provided a 'technical vision,' rather than analysing how Meccano changed many times during the interwar period. Other examples can also be found in those history of computing publications that have attempted to describe the instrumentality of the differential analyser as an analogue computer, without engaging with the 'nuts and bolts' of how the machine worked, or what the impact of the 'analogue gap' has been on how it has been written about previously.

The distance from Meccano and the Meccanomen in previous literature is particularly difficult to explain as there are many records relating to Meccano and the Hornby brands (B/ME/NRA/36257) on the site of the former Binns Road Meccano factory. These include the financial accounts of Meccano from 1920-1980 (B/ME/6/1-6), extensive newspaper clippings, and microfilms (B/ME/6/30-35), and press information and marketing materials (B/ME/6/36-40). Alongside these archives are numerous website repositories run by enthusiasts, which contain entire collections of 'mainstream' Meccano instruction manuals,[85] marketing

[85] Meccano Instructions Manuals, https://meccanoindex.co.uk/Mmanuals/Index.php [accessed 10 September 2016].

materials,[86] and the *Meccano Magazine*.[87] It is also possible to purchase the entire back catalogue of all of the 'alternative' Meccanomen publications since 1965 for a relatively low cost online.[88] Alongside these written sources and images, a significant primary source that I accessed was the Meccanomen themselves. After sitting down with 126 of them for several hours each, it became apparent that their perspectives on the history of Meccano and British engineering have not previously been collected in a systematic way. The exploration of 'mainstream' and 'alternative' Meccano sources, alongside the voices of the Meccanomen, provided me with lots of useful information and more potential stories than I could do justice to in a single thesis. Instead, it uses these sources to focus on the story of Meccano as a changing scientific-cultural object before the Second World War, and how it split into two versions after 1965. Bringing together these disparate 'mainstream' Meccano and 'alternative' Meccanomen sources allows this thesis to tell the story of Meccano as a physical, conceptual, and cultural object that was used by Hartree and Porter to build their original differential analyser in 1934.

In order to engage with the 'nuts and bolts' instrumentality of the original Meccano differential analyser, Chapter Two collates the primary sources on the machine from the Science Museum Archives at Kensington and Wroughton, alongside those from the Science and Industry Museum. First and foremost, the Science Museum contains the Trainbox object (Sc. M. 1949-134), various curatorial labels and documents (Sc. M. 1949-134/2:4), associated collection paperwork and correspondence (Sc. M. 1949-134/3, and Sc. M. 8640/1/1), and subsequent curatorial documentation (Sc. M. 1949-134/5). These were also useful to learn

[86] Meccano Marketing, http://www.nzmeccano.com/image-4767&string=meccano+usa [accessed 12 September 2016].
[87] *Meccano Magazine*, http://meccano.magazines.free.fr/ [accessed 23 October 2015].
[88] Meccano Shop, https://www.meccanoshop.co.uk/cd-rom-s-c102x3029690 [accessed 3 August 2016].

about the life of the Trainbox as a collected object and contained hints about how it has been used to tell a variety of different stories since it was collected in 1949.

However, to effectively analyse how the Trainbox has been changed as a result of the developments at the museum, I also accessed Science Museum Group acquisition policies (SLG 54/9), collecting management policies (SCM/1991/1192, SCM/1993/0984, and SCM/2006/0510/245/061), research policies (SCM/1995/1379, SCM/1996/0913, and SCM/2001/0780) and object handling procedures (SCM/1999/1765). These documents helped to provide context on some of the changes that have been made to Trainbox in different galleries. They also revealed how the development of the Model Walkway in the 'Making the Modern World' exhibit led to a new 'universal language' (SM Informal Collection, 2000), which helped inform the analogy of ventriloquism used in Chapter Four to discuss how the museum has changed the voices of the Trainbox.

There are many sources relating to the other Meccano and non-Meccano differential analysers inspired by Hartree and Porter's original, which are explored in Chapter Three. These include Hartree's post-war monograph (MSO17.502), John Lennard-Jones' submission to build a bespoke differential analyser (LEJO/5), and the Cambridge Faculty Report (LEJO/6/1-2), which describe the applications and uses of other differential analysers. However, to be able to tell the stories and applications of non-academic wartime analysers, I also contacted Pocklington School, who provided me with the Physics Practical Notebook that belonged to William Worthy from their archives. Alongside Worthy's school notebook, I accessed wartime sources from the UK National Archives (DEFE 15/751-C20779) and the Museum of Transport and Technology Auckland (MOTAT) (PUB-2019-8). I was also directed to pertinent publications about machines by staff at the Institute of Actuaries and the Chilton Computing Centre. While the wartime stories of US differential analysers have been previously explored in the context of the history of computing, Chapter Three brings together these scattered sources on British analysers for the first time, exploring their applications and legacy, in an attempt to close the ‘analogue gap’ in the history of computing.

The Science Museum’s Wroughton archives also contained copies of Arthur Porter’s Ph.D. thesis and other early work with the original Meccano differential analyser (Sc. M. 1972-235), and documentation relating to the construction of the Manchester machine (Sc. M. 1972-236). These were useful to learn more about the early applications, and the challenges Metropolitan Vickers had in making the Manchester machine work and maintaining it. This information proved invaluable when I later attempted to historically reproduce the original Meccano differential analyser as the Kent machine. The separation of the Manchester machine into two parts has also meant that SIM contains many sources relating to the technical aspects of Hartree and Porter’s two analysers. These include an integrating unit from the Manchester machine (Y1995.145.2), half of the Manchester machine (Y1988.447), engineering drawings of the machine and its torque amplifiers (YA1987.6/MSO251/1-6), and correspondence between the Science Museum and SIM about the machines (MSO237/26). Alongside these, I was fortunate to be granted access to an interview that amateur historian Tim Robinson conducted with Arthur Porter shortly before his death (X4583.2008). Porter’s reflections, alongside these sources from the Science Museum and SIM, helped me to understand more about how the different units in the machine functioned, the calibration issues experienced by its operators, and the concept of ‘accuracy bias’ (explored in Chapter Two). It was also a crucial source in the project to historically reproduce the original differential analyser as the Kent machine in Chapter Seven.

Finally, the thesis draws on my experiences of reproducing and presenting the Kent machine at various institutions within the UK and US. Through constructing, using, and demonstrating the machine, I learned a lot about the strengths and weaknesses of Meccano as a construction medium, the traditions of Meccano, and the tacit knowledge required to make the analyser work. Chapter Seven establishes that engaging in 'shared authority' as a means to shape the public history of the Kent machine resulted in interactions with academics and enthusiasts that demonstrated how these types of machines still have relevance and potential for use in a world defined by digital computers. This knowledge and these experiences would not have been possible to gain without reproducing the original differential analyser as the Kent machine. The process of reproducing the machine allowed me to experience the role that historians increasingly need to play, as an enabler of the public, with whom I worked to co-curate a new public history for this reconstructed and historically reproduced Meccano analogue computer.

7. Thesis outline

My vision for the structure of the project is that it resembles an (imagined) museum exhibit in the Science Museum, with each chapter telling two stories – of Meccano and Computing in different contexts – that culminates in the reproduction of the Kent machine in Chapter Seven on display to an audience in the Science Museum (see figure 11).

Figure 11: An image of the completed Kent machine after the first public demonstration at the University of Kent in October 2018. (Left to right), the author, Ian Henwood, and Matt Goodman. (Image taken by Karen Brayshaw).

Each chapter in the thesis uses different historical approaches and techniques to analyse the identities of the original Meccano differential analyser as a Meccano model and an analogue computer. They are written in a way that makes sure that the stories about the two identities of the object are told in parallel and intersect when needed. This is to help the reader better understand the original Meccano differential analyser as an assemblage of changing identities (as a Meccano model and analogue computer), contexts (as a research instrument, teaching tool, and museum object), and audiences (in the *Meccano Magazine*, academic publications, and in the Science Museum). It is also important to note that this thesis has not been written to be a technical document about differential analysis or the method of mechanical integration. I have done my best to grasp the technical aspects of the analyser, but my training and scholarly contributions to these subjects are as a historian of science.

Chapter One begins with the story of how Frank Hornby invented Meccano in 1901 as 'Mechanics Made Easy,' a child's educational toy comprised of standardised physical parts. The chapter goes beyond exploring Meccano's unchanged physical pieces, borrowing elements of Roland Barthes' semiotic approach to the construction of meaning to analyse its marketing materials, instruction manuals, and the *Meccano Magazine*. Through these analyses, the chapter challenges the conventional public history of Meccano that situates it as a synecdoche for British engineering. It does this by demonstrating that Meccano was not a static object, but was developed from a toy into a training tool for would-be engineers, an international emblem of fan-participation in international science and engineering before the Second World War, and finally a nationalistic object of British engineering after 1935. It also introduces the process of 'Meccano-fication,' whereby aspects of articles and images were changed to make it easier for readers to understand and engage with complex objects. Deconstructing these changing cultural meanings of Meccano also provides context for why Douglas Hartree and Arthur Porter used it to build their differential analyser in 1934. It also demonstrates that the notion that Meccano is a synecdoche for British engineering (prominent in academic histories and Kroto's perspective) is based on the nationalistic version of the object developed in the final years before the Second World War.

Chapter Two explores the material and immaterial aspects of Hartree and Porter's original differential analyser as an analogue computer. It begins by establishing the context that led to the creation of the mechanical method, as well as exploring the concept of accuracy. It then explains the 'nuts and bolts' realities of the original differential analyser and contrasts them to the different stories that the machine was used to tell before the Second World War. It highlights its simultaneous presentation as a 'demonstration object' with a 98% accuracy rate and a 'Mechanical Marvel' in 1934, and how these led it to have an inflated belief in its usefulness and accuracy that was incongruent with the realities of the mechanical method of the machine. It finishes by exploring how this reduced its usefulness and applicability before the Second World War.

Chapter Three brings together a series of differential analysers constructed and used in Britain before, during, and after the Second World War for the first time to provide a new set of case studies. It uses the stories, applications, and legacy of these machines as case studies to better understand the benefits of these analogue computers (rather than their failings) in relation to digital methods. The chapter also uses these stories to provide context for why Hartree used pieces from the original differential analyser to build the 'Trainbox' in 1947. Through these case studies, it establishes that his decision was not unique, but was part of a trend where smaller mechanical analysers were increasingly used for teaching purposes as the war progressed, while larger mechanical and electromechanical variants continued to be developed in parallel with digital methods.

Chapter Four introduces the analogy of ventriloquism to build on previous museum and material culture literature by presenting an examination of the changing stories that a particular object — Douglas Hartree's 'Trainbox' — has been used to tell in the Science Museum, London. The analogy of the object having a 'ventriloquised' voice is used to illuminate how objects can carry the various meanings, interests, and prejudices (conscious and unconscious) of the human actors involved in their creation, collection, and display. The chapter describes how the voices 'ventriloquised' through Hartree's rebuilt 'Trainbox' have imbued this later version of the machine with the physical and instrumental functions of the original differential analyser to make the object ‘fit’ with varying stories of computation, differential analysis, and models. It concludes that the voices ventriloquised through the Trainbox impact subsequent presentations of the object, which has turned it into the ‘material polyglot’ that sits in the *Information Age* gallery of the Science Museum today.

Chapter Five explores how Meccano has changed since the Second World War. It demonstrates how changes made to ‘mainstream’ Meccano outfits and the *Meccano Magazine* after the Second World War marginalised the older Meccano boys, who responded by developing their own ‘alternative’ version of the hobby in 1965. Subsequent sections then consider the parallels and contrasts between the physical pieces, themes, and publications of these two Meccano cultures. They also establish the different fan-techniques that the Meccanomen used to protect their nostalgia and memories of Meccano, analysing how their passion, fandom, and desire to return to a ‘golden age’ of their hobby led them to alter aspects of their ‘alternative’ version of Meccano. These sections then explore how these changes moved the Meccanomen’s version away from different versions of Meccano explained in Chapter One, despite the belief that their version was something ‘Hornby would have wanted.’ After telling the diverging stories of the ‘mainstream’ and ‘alternative’ versions of Meccano, the chapter concludes by asking two questions. The first is whether the conventional public history of the ‘alternative’ version of Meccano has impacted how contemporary enthusiasts compose their perspective of their hobby. The second counterfactual question asks which of the two versions that Hornby ‘would have wanted’ if he were alive today.

Chapter Six combines principles from both oral history and public history scholarship to engage in and analyse a series of interviews and discussions with members of the International Society of Meccanomen. The participatory approach taken in interviews was designed to provide a space where I could work with them to co-curate ‘participant historiographies’ that critiqued the way that previous public histories of Meccano have been written. Their voices challenge three aspects of the conventional public history of Meccano, including the pre-war ‘golden age’ of Meccano, the ‘golden age’ of British engineering, and the widely-held belief that the demise of Meccano caused a British decline. The analysis of their responses establishes that rather than a consensus of views that fits with the conventional public history of Meccano, they composed answers that did not fit and were based on their personal experiences, which led them to be split into distinct groups. The chapter also explores why the Meccanomen did not experience a sense of discomposure when giving these answers that deviated from the conventional public history of their hobby.

Chapter Seven analyses the benefits and challenges associated with historically reproducing Douglas Hartree and Arthur Porter’s original Meccano differential analyser as the ‘Kent machine.’ It analyses the historiographical significance of the tacit and gestural knowledge that the Kent machine helped to recover, which is absent in primary textual sources. It then examines the challenge of maintaining historical fidelity with the Kent machine, and how actively reproducing errors from the *Meccano Magazine* and solving them impacted the tacit knowledge that was recovered. It concludes by discussing the different conflicts of ‘shared authority’ that occurred during the demonstrations of the Kent machine, and how these were used – and to an extent ventriloquised – to cultivate a new public history for this object, before it is accessioned by the Science Museum in 2020.

The exploration of the original Meccano differential analyser in this thesis demonstrates the challenges of object identity. It requires us to question how we understand ourselves in relation to the material world, Meccano, objects in museums, and the role of analogue computers in the history of computing. It adds to the scholarship on these topics across the first six chapters by deconstructing the internal and external assemblages of the object. This approach provides an opportunity to reflect on how we understand different aspects of scientific objects, how users have engaged with them, and how the relationships between these internal and external assemblages have changed over time. The final chapter then describes how I used these new understandings of the original object as an assemblage of internal and external assemblages to reconstruct it as the Kent machine. By deconstructing and reconstructing the original Meccano differential analyser, the thesis explores how 'we make things, things make us.'[89]

[89] D. Miller (ed.), *Materiality* (Duke University Press, 2005), p. 256.

Chapter One – Meccano and the *Meccano Magazine*, 1901-1939: From a 'Boy's Toy' to an 'Aspirational Emblem of Fan-Participation'

1. Introduction

In 2001, Sir Harry Kroto composed his perspective of Meccano on the BBC radio programme *Desert Island Discs*. He asserted that his Nobel Prize-winning work on the discovery of fullerenes had been based on the skills he had learned with Meccano as a child, telling the interviewer that 'You imagine building molecules as if they were bits of Meccano.'[90] Kroto then argued for the usefulness of Meccano at the expense of Lego, saying that:

> Meccano teaches engineering and architectural skills in a way that Lego doesn't. If we had more Meccano, we would have railways that worked. There would be more engineers with a better basic understanding…I think 99 per cent of all British engineers were brought up on Meccano. Then came Lego.

Kroto then correlated the falling popularity of Meccano after the Second World War with the 'demise of British engineering,' before asserting that its disappearance after 1981 had resulted in a decline in the quality and quantity of British engineers, something he called a 'disaster of modern life.'[91] Kroto's perspective was reprinted in a series of newspapers at the time, where it was supported by Derek Panteny, the managing director of Nikko (the UK distributor of Meccano).[92] Panteny's comment that 'I think Sir Harry is making a fair point. It's

[90] Fullerenes are spherical allotropes of carbon that are spherical or tubular in shape. A nickname for the fullerenes that Kroto helped to discover is 'buckminsterfullerene' after their similarity in shape Buckminster Fuller's geodesic domes.
[91] Kroto's interview in which he discussed the 'demise of British engineering' was on a BBC Radio 4 episode of *Desert Island Discs,* https://www.bbc.co.uk/programmes/p00948nr [accessed 4 July 2016].
[92] L. Jordanova, *History in Practice* (London, 2000), p. 126.

the enthusiasm that Meccano generates in children,' helped to legitimise Kroto's synchronic perspective that extrapolates a version of Meccano from a specific point in time to the entire history of the object, and make it part of the official public history of Meccano.[93]

Kroto's perspective represents what Benedict Anderson described in *Imagined Communities: Reflections on the Origin and Spread of Nationalism* (1983) as an 'imagined community.' Anderson developed the concept of 'imagined communities' to better understand the formation of nationalistic groups in the twentieth century. He based the development of these groups around what he described as 'particular solidarities,' which are emergent attributes of something that result in a specific social order.[94] Within this context, Kroto's presentation of Meccano as a synecdoche for the development and decline of British engineering after the Second World War is built on one of these particular solidarities. This solidarity is based on the conventional public history of Meccano that previous historians have written, which situate it as an unchanged educational toy since it was invented in 1901. Based on this, the chapter will explore the development of Frank Hornby's invention from 1901 to 1939 to challenge Kroto's synchronic perspective as part of the conventional public history of Meccano. It will demonstrate that the history of Meccano before the Second World War is more complicated, and that rather than an unchanging object, it was an educational toy, a training tool for would-be engineers, an aspirational emblem of fan-participation in international science and engineering, and became a nationalistic object before the Second World War. It will establish that the conventional public history of Meccano, from which Kroto

[93] Anon., 'Why Britain needs more Meccano and less Lego': https://www.telegraph.co.uk/news/uknews/1333215/Why-Britain-needs-more-Meccano-and-less-Lego.html [accessed 28 June 2017]. The declinist aspects of Kroto's comments will be addressed further in Chapter Six.
[94] B. Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism* (Verso, 1983), p. 133.

derived his perspective is based on the version of Meccano developed after 1935, when Hawks departed as editor of the *Meccano Magazine*.

The third section will analyse the development of Meccano from 1901 to 1916, establishing that Hornby initially created 'Mechanics Made Easy' as a child's educational toy, before changing it into a training tool for would-be engineers in the period 1916-1921. The fourth section explores how Hornby used his editorship of the *Meccano Magazine* to regulate these two versions of Meccano for different groups of users, before the fifth demonstrates how Hawks' developed it by removing simple and straightforward models in favour of more complex and scientific machines. It also establishes how Hawks developed the language and signifiers in the *Meccano Magazine* and Meccano instruction manuals to ensure that less-wealthy users could continue to be part of the aspirational community of users. It explores how these changes were partly due to Hawks' authorship of popular science books and observes how this impacted his editorship of the *Meccano Magazine.* The sixth section then considers how Hawks' popular science books and role in developing another construction toy, 'Construments,' were reflected in how Meccano continued to be changed and presented in the *Meccano Magazine*. It highlights how Meccano began to be presented in a simplified way via the process of 'Meccano-fication,' exploring how this process was utilised to simplify the complex objects in the magazine (including Douglas Hartree and Arthur Porter's differential analyser). It then explains how 'Meccano-fication' was used to allow all users to aspire to (and believe that they were participating in) the international science and engineering featured in the *Meccano Magazine* from 1930 and 1935, despite the majority being unable to afford the Meccano sets used to build these complex objects. It then demonstrates how Meccano became a nationalistic object of British engineering in the final years before the Second World War, and that it was this version that Kroto's synchronic perspective is based on.

2. Context

The four main sections of the chapter will do more than simply describe how the physical pieces of the toy developed in this period. The reason for this is that aside from the colour and finish, the specifications of the physical pieces of Meccano did not change between their invention in 1901 and the onset of the Second World War (see figure 1.1).[95] While many new pieces were added to Meccano sets in this period, they all followed the strict design principles of the original pieces that Frank Hornby had described as ‘standardised’ and ‘uniform’ in his 1901 patent.[96]

Figure 1.1: An image that demonstrates that standardised nature of Meccano pieces between 1901 and 1934. The only change to these pieces was their colour (and finish, which changed from tin-plating to nickel-plating in the 1920s). (Image reproduced from http://www.nzmeccano.com/AboutPaint.php).

The constructionist approach to representation and meaning asserts that the physical pieces of an object carry no inherent meaning, but that they take on meaning by becoming objects of knowledge within a particular culture. It explains that meaning is produced through various representational systems, relating to signs and symbols, which are used to represent concepts, ideas, and feelings.[97]

There are two primary semiotic approaches in constructionism, belonging to Ferdinand de Saussure and Roland Barthes.[98] Saussure’s work explores how shared meanings

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[95] Although the colours of the pieces were arbitrary before the Second World War, they carry much more significance for the meaning of Meccano in the post-war period, which is discussed further in Chapter Five.

[96] Patent No. 587-1901. F. Hornby, ‘Improvements in Toy or Educational Devices for Children and Young People,’ (9 January, 1901), p. 1.

[97] S. Hall, J. Evans, and S. Nixon (eds.), *Representation* (Open University, 2013), p. xvii.

[98] I considered using other approaches to how meaning is constructed in objects, including du Gay’s ‘semantic networks,’ and Foucault’s discursive approach. These include: P. du Gay, S. Hall, L. Janes, H. Mackay, and K. Negus, *Doing Cultural Studies: The Story of the Sony Walkman* (Open University, 1997); M. Cousins, and A. Hussain, *Michel Foucault* (Basingstoke, 1984); and M. Foucault, *The Archaeology of Knowledge* (Routledge, 2002). While these all offer interesting ways of understanding objects, I decided to use a semiotic approach to try and better understand Meccano in this thesis.

are produced through the representational system of signs. He explains that language is the prime example of how arbitrary signs are organised into a medium through which we can collectively make sense of things.[99] However, despite its usefulness as an explanatory mechanism for how meaning is constructed with language and signs, Saussure's structuralism has received criticism for placing too much emphasis on the signified meaning constructed by the signifier and the object, often at the expense of the interactive relationship between these different aspects over time.[100] To avoid this criticism, this work instead borrows from Barthes' work to explore how different signified meanings of Meccano have interacted and changed over time.

Barthes adopted aspects of Saussure's semiotic approach in his explanation of how meaning and modern cultural myths are constructed. However, unlike Saussure, Barthes believed that visual images could be treated and read as text, which he did in his semiotic analysis of front cover of the *Paris Match* magazine from 1955 (see figure 1.2). Barthes' approach led him to read the front cover of this magazine as if it were text that carried meaning. He explains that the young black soldier on the front cover represents a signifier, which, in concert with the notions of imperialism and military conflict, signified to the reader the ideological message that 'France is a great empire, that all her sons, without any colour discrimination, faithfully serve under her flag.'[101] His approach was unique as it separated the descriptive denotation of an object's meaning from its connotation. Put simply, Barthes argues that the images on a magazine cover (in this case, the soldier in an army uniform) signified more to the viewer than the sum of its parts. He asserted that this approach provides

[99] S. Hall, J. Evans, and S. Nixon (eds.), *Representation* (Open University, 2013), p. 3.
[100] These critiques of Saussure's structuralist approach include, P. Thibault, *Re-reading Saussure* (Routledge, 1996); and B. Gasparov, *Beyond Pure Reason* (Columbia University Press, 2012).
[101] R. Barthes, *Mythologies* (London, 1972), pp. 116:119.

a method to explain why 'fragments of ideology' and wider cultural myths gain salience in culture.[102]

Figure 1.2: An image of the cover of the Paris Match magazine that Barthes analysed to demonstrate how signifiers provide meaning via denotation and connotation. (Image reproduced from R. Barthes, Mythologies (London, 1972)).

Barthes' semiotic approach to reading images as text features throughout this chapter and is used to analyse the changing signifiers and signifieds of Meccano and the *Meccano Magazine* in relation to the different versions of Meccano (as a toy, training tool, and aspirational emblem). The sections will examine how Meccano was used to tell different stories through various marketing materials between 1901 and 1939. These include early set

[102] R. Barthes, *The Elements of Semiology* (London, 1967), pp. 91-92.

cartons, shop signs, instruction manuals, and the *Meccano Magazine*, which was initially created in September 1916.

The *Meccano Magazine* is the single richest written source about Meccano, providing monthly examples of how Meccano changed, in over 223 issues published from 1916 to 1939.[103] In contrast to the standardised physical pieces of Meccano, the structure, content, and design of marketing materials changed many times, with the *Meccano Magazine* having four editors and numerous redesigns before the Second World War. The publication run of the magazine under the first two of these editors (1916-1935) is the period primarily analysed in this chapter. Frank Hornby, the original inventor of Meccano, created and edited the *Meccano Magazine* from 1916 to 1921. He then passed this responsibility to Ellison Hawks, who continued as editor until 1935, one year after Hartree and Porter's Meccano differential analyser was featured in the magazine.

I have also chosen to explore the *Meccano Magazine* as it (along with other magazines) has been extensively used by historians to analyse changes in culture and society. Peter Bowler used magazines and other publications in *Science for All* (2009) to demonstrate that the increase in scientific content in magazines before the Second World War was to satisfy a changing public desire in Britain.[104] His exploration of the changing content of the *Meccano Magazine* led him to suggest that the success of Meccano was the result of it being presented as a 'juvenile equivalent of adult magazines such as *Armchair Science*…providing a clear vision of science and engineering.'[105] Bowler's analysis of Meccano contains aspects of

[103] As well as being an excellent and regular repository of the changing hobby of Meccano before the Second World War, each issue has been scanned and is available to view online at (http://meccano.magazines.free.fr/index.htm).
[104] P. Bowler, *Science for All: The Popularisation of Science in Early Twentieth-Century Britain* (University of Chicago Press, 2009).
[105] P. Bowler, '*Meccano Magazine:* Boys' Toys and the Popularisation of Science in Early Twentieth-Century Britain,' *British Journal for the History of Science: Themes*, Vol. 3, (2018), pp. 129-130.

Kroto's synchronic perspective, discussing how Meccano represented an unchanging vision of engineering in Britain. Similar to Bowler and Kroto, Ruth Wainman uses the *Meccano Magazine* to make the argument that Hornby's creation provided a 'technical vision of boyhood' during the interwar years in her article, '"Engineering for Boys": Meccano and the Shaping of a Technical Vision of Boyhood in Twentieth-Century Britain,' (2017).[106] The exploration of how Meccano changed in this chapter will demonstrate that these previous historical perspectives of Meccano – as an unchanging engineering object – are built on the same 'particular solidarity' as Kroto's synchronic perspective and the conventional public history of Meccano, which asserts that the Meccano boys used the object in a single way as a homogenous group of users.

In contrast to this previous research, this chapter will demonstrate the different ways that Meccano changed in the period leading up to the Second World War. It will borrow from Will Tattersdill's *Science, Fiction, and the Fin-de-Siècle Periodical Press* (2016) to explore how Hornby and Hawks used their 'organising power' as editors to shape Meccano and the magazine in their own images. It will establish that the *Meccano Magazine* is an important source from a literature and science perspective as it helps to establish that the identity of Meccano was based on multiplicity.[107] The sections will also explore how Hornby and later Hawks changed the signifiers in the magazine and in other marketing material to regulate the attributes they wanted different groups of Meccano boys to possess during their tenures. These signifiers include the development of characters, including the 'Meccano boy,' the 'father-figure,' and the 'eminent engineer,' which demonstrate how Meccano was

[106] R. Wainman, '"Engineering for Boys": Meccano and the Shaping of a Technical Vision of Boyhood in Twentieth-Century Britain,' *The Journal of the Social History Society*, Vol. 14 (3), (2017), p. 381.
[107] W. Tattersdill, *Science, Fiction, and the Fin-de-Siècle Periodical Press* (Cambridge University Press, 2016), pp. 8-9.

changed.[108] The chapter will use these changing signifiers to indicate how the magazine and other marketing materials were used to address readers in a range of voices and change Meccano from a boy's toy, to a training tool for would-be engineers, and into an aspirational emblem of fan-participation in international science and engineering.

[108] Content of the following magazines are used to analyse the development of the language and signifiers used to change the meanings of the toy: *Meccano Magazine,* Vol. I, No. 1, (September, 1916) - Vol. LII. No. 7, (July 1967).

3. From 'Mechanics Made Easy' to 'Meccano': The Boys' Toy

The first sets of 'Mechanics Made Easy' (the original name of Meccano until 1907) contained 17 distinct pieces. Hornby's original patent states that the 'standardised pieces' of his invention met a 'long-felt want among young people for some device, which will enable them to construct mechanical objects without the laboriousness of turning, boring, and careful adjustment.' Hornby also explains that he had designed the components to be 'reduced copies' of the real-life mechanical components used by engineers and inventors at the time, and that his intention was for it to be 'toy or educational device for children' that provided a mechanical education.[109] The concept of childhood was relatively new at the time as previously, children were understood as adults-in-waiting.[110] However, the same social reforms that had helped to separate childhood from adulthood had also resulted in the 'boy-problem'; a moral panic that the devil would find work for children's idle hands.[111] The language in Hornby's patent suggests that he invented Mechanics Made Easy as a solution to the 'boy problem,' as he believed that through developing their 'mechanical education,' children could raise themselves to a position of usefulness as adults.[112] This was also reflected in the *Meccano Magazine*, which stated that 'Meccano is primarily engineering in miniature… [it] represent[s] real engineering units.'[113]

The notion that Hornby had initially developed Meccano as a solution to the boy-problem is also suggested at in an article he wrote for the January 1932 issue of the *Meccano*

[109] Patent No. 587-1901, F. Hornby, 'Improvements in Toy or Educational Devices for Children and Young People,' (9 January, 1901), p. 1.
[110] D. B. Clarke, M. A. Doel, and K. M. L. Housiaux, *The Consumption Reader* (Routledge, 2003), p. 197.
[111] F. Trentmann, *Empire of Things* (Allen Lane, 2016), p. 488; and A. L. Alcorn, 'Flying into Modernity: Model Airplanes, Consumer Culture, and the Making of Modern Boyhood in the Early Twentieth Century,' *History and Technology*, 25 (2), (2009), p. 116.
[112] A. McReavy, *The Toy Story: The Life and Times of Inventor Frank Hornby* (Ebury Press, 2002), p. 34.
[113] R. Barthes, *Mythologies* (London, 1972), p. 53; and E. Hawks, 'The Lighter Side of Meccano,' *Meccano Magazine*, Vol. VII, No. 3, (March, 1922), p. 1.

Magazine. In it, he said that his interest in mechanics and engineering principles had happened 'by accident' after reading [Samuel Smiles'] *Self-Help* as a young man, which inspired him to invent Meccano. He explained that '...nothing that I have read since has exercised such a strong and lasting influence on me.'[114] Smiles' work uses various examples of 'Men, in this and other countries, [who] by dint of persevering application and energy… [have] raised themselves from the humblest ranks of industry to eminent positions of usefulness and influence in society' to highlight the virtues of a mechanical education with the hands.[115] Smiles, in his later book, *James Nasmyth, Engineer: An Autobiography* (1883), provided an example of this type of great man, who had achieved an eminent position based upon the learning he had achieved with his eyes and fingers. These books told the reader that the fingers '…are the chief sources of trustworthy knowledge as to all the materials and operations which the engineer has to deal with...No book knowledge can avail for that purpose.'[116] Therefore, Hornby's invocation of Smiles' rhetoric supports the idea that he initially created Mechanics Made Easy as an educational toy that was the physical embodiment of Smiles' nineteenth-century masculine rhetoric of self-improvement.

The early sets of Mechanics Made Easy were packaged in cartons showing images of toy cranes, cars, and in the centre, a picture of a boy and a girl (see figure 1.3). The choice to feature two middle-class children on the branding would have signified to parents that Mechanics Made Easy was a toy that produced productive members of society through educational play.[117]

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[114] F. Hornby, 'The Life Story of Meccano: Romance of the World's Greatest Toy,' reproduced in ten instalments in the *Meccano Magazine*, Vol. XVII, No. 1, (January 1932), p. 6.
[115] S. Smiles, *Self-Help* (John Murray, 1859), pp. 12-13.
[116] S. Smiles (ed.), *James Nasmyth: An Autobiography* (London, 1883), p. 97.
[117] G. McCracken, *Culture and Consumption: New Approaches to the Symbolic Character of Consumer Goods and Activities* (Indiana University Press, 1990), p. 104.

Figure 1.3: An image of one the earliest sets of Meccano from 1901, known as 'Mechanics Made Easy.' (Image reproduced with permission of R. Marriott, *Meccano* (Shire Publications, 2016)).

Through consuming these sets, the users of Meccano did what McCracken describes in *Culture and Consumption: New Approaches to the Symbolic Character of Consumer Goods and Activities* (1990), which was to 'construct social identities and relations out of social resources with which they engaged as skilled social agents.'[118] Thus, consumption of these sets was made into an essential part of the user's identity, with users being told (in relation to buying and consuming the toy), 'You have never finished.'[119] The initial success of these sets led Hornby to develop a series of sequentially bigger sets and 'interval sets,' which allowed users to strive for larger sets while still being able to own and consume the toy incrementally. The cheaper interval sets would have also increased the number of parents who could conspicuously demonstrate the ability to give their children the means to transition to adulthood.[120] This analysis of these early sets of Mechanics Made Easy – as educational toys

[118] D. Slater, *Consumer Culture and Modernity* (Polity Press, 1997), p. 4.
[119] F. Hornby, 'The New Meccano Manual of Instructions,' *Meccano Magazine*, Vol. I, No. 2, (November, 1916), p. 2.
[120] R. S. Mason, *Conspicuous Consumption: A Study of Exceptional Consumer Behaviour* (Gower, 1981), p. 150.

that parents wanted their children to consume based on their 'self-help' principles – contrasts with both Kroto's perspective and the conventional public history of Meccano that situates it as an engineering tool linked to British engineering and decline. It also contrasts to Bowler's and Wainman's previous analyses of Meccano as an unchanged engineering object.

The status of Mechanics Made Easy as a simple educational toy began to change after the 1902 Balfour Education Act, which increased the availability of elementary education in the UK. Hornby made sure that the increased public emphasis on children's education was reflected in Meccano Kindergarten sets, which began to include drawing books from 1908 (see figures 1.4a and 1.4b).

Figure 1.4a: The Kindergarten Drawing Books added to Meccano sets in 1908, designed to encourage users to draw out their models schematically before building them. (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals.php?id=1553515633).

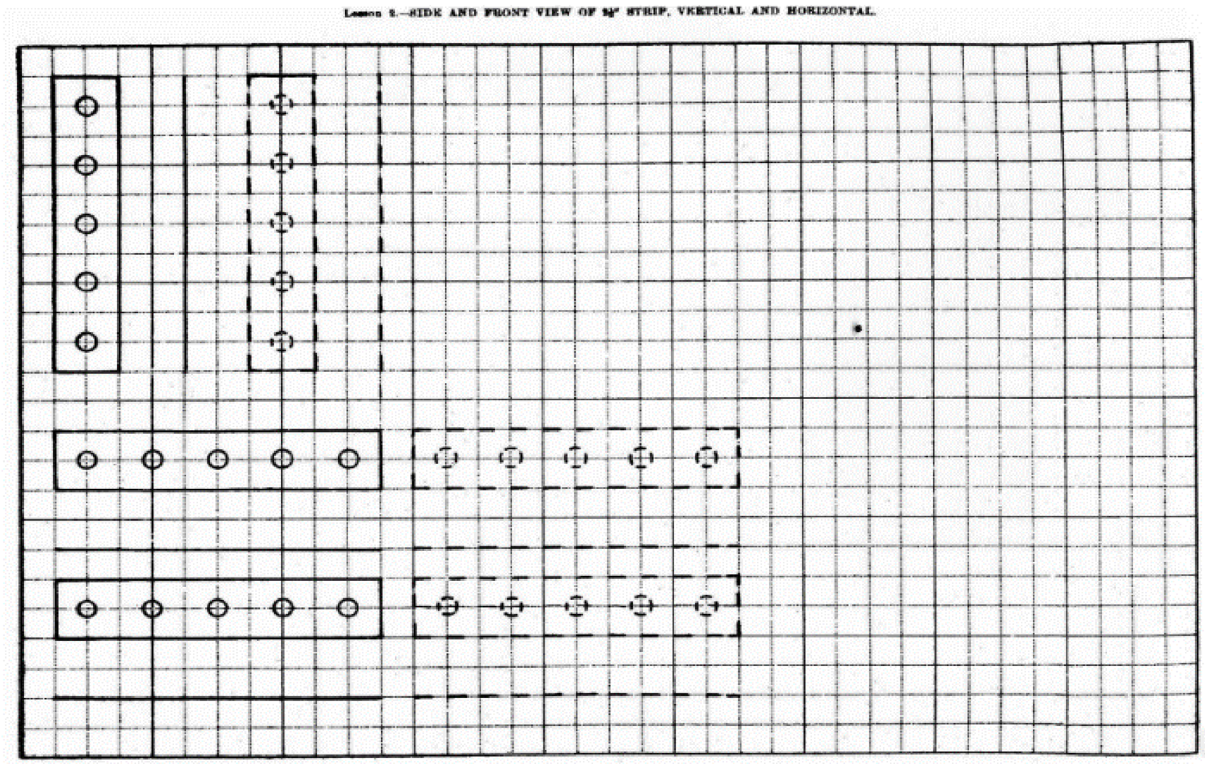

Figure 1.4b: The Kindergarten Drawing Books added to Meccano sets in 1908, designed to encourage users to draw out their models schematically before building them. (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals.php?id=1553515633).

These notebooks were included to allow users to draw models schematically before they built them, which allowed them to mimic the practices of engineers and architects.[121] It was at the same time as Hornby placed an increased emphasis on education that he also changed the name from Mechanics Made Easy to Meccano. The new name shifted how Meccano was advertised to users, as the design of the new Meccano instruction manuals began to change. While the images of the boy and girl still featured – signifying that Meccano was a children's toy – new elements were added to these manuals, which changed the intended audience and use of Meccano (see figure 1.5).

[121] For more on the Balfour Act, refer to D. R. Pugh, 'English Nonconformity, Education and Passive Resistance 1903–6,' *History of Education*, Vol. 19 (4), (1990), pp. 355-373; and R. Cooter, *In the Name of the Child: Health and Welfare, 1880-1940* (Routledge, 1992).

Figure 1.5: An image reproduced from an instructions manual of a Meccano set from 1908. (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Intro.php?id=1553108055).

The addition of the 'Best Boy's Toy' circular sticker in the top right-hand corner of the packaging indicates that Hornby was moving Meccano away from being a toy for boys and girls, and into a 'boy's toy.' Although a girl features on this instruction manual, she is passive and obscured by the more active boy in school uniform, which was used to signify education and his middle-class status.[122] After this 1909 redesign, the new Meccano manuals remained virtually unchanged for the next 25 years until the introduction of lettered Meccano outfits (see figure 1.6).[123]

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[122] Girls were removed from Meccano marketing and manuals the following year and would not return until 1979.

[123] Although girls had featured on their 'own' Hornby brands in the interim, including Dinky Toys and Prima Meccano, they were not returned to Meccano branding until 1979. This was in response to the decreasing popularity of the toy, which led Meccano Ltd. to develop unisex packaging that was 'specially designed for maximum customer impact by showing boys and girls "having fun" building with Meccano. Meccano is a "fun" product which, in the modern world, appeals to girls as well as boys, and the new approach shoots the message home at a glance.' This information is reproduced from Liverpool Records Office, B/ME/6/36, Meccano 'Press Information.'

Figure 1.6: An image reproduced from an instructions manual of a Meccano set from 1910. (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-10).

The presence of two boys and their model on these manuals signified that Meccano was a 'boy's toy.' It provided a further example of the 'Meccano boy' character, a middle-class individual who is playing and learning through building Meccano models. However, while the design of these manuals did not change, their content and the different way they presented Meccano to users began to change dramatically.

The first major development came in 1909 when Hornby developed the educational aspect of Meccano by introducing *The Hornby System of Mechanical Demonstration*. These sets contained both Meccano and other bespoke pieces that provided schools with a cheap set of instruments that they could use to create scientific objects and experiments in science lessons at school. The 1913 Meccano Instructions Manual told users that this new system 'provides an economical and yet very effective series of apparatus for demonstrating the main elementary fundamentals of mechanics and mechanical science.'[124] It also states that the added value of models made from the *Hornby System* was that they could be taken to pieces unlike the present models in secondary schools, and that this process of dismantling and building helped the user to 'develop his constructive facilities.' It concluded by telling readers that 'experimental models constructed from "Hornby" system parts will be found to be of quite as high a degree of accuracy as apparatus costing many times as much.'[125] One of the models that the demonstration set could be used to construct was the 'Universal Crosshead,' which was described as something that could be used to explain and 'demonstrate pumps and similar mechanisms' (see figure 1.7).

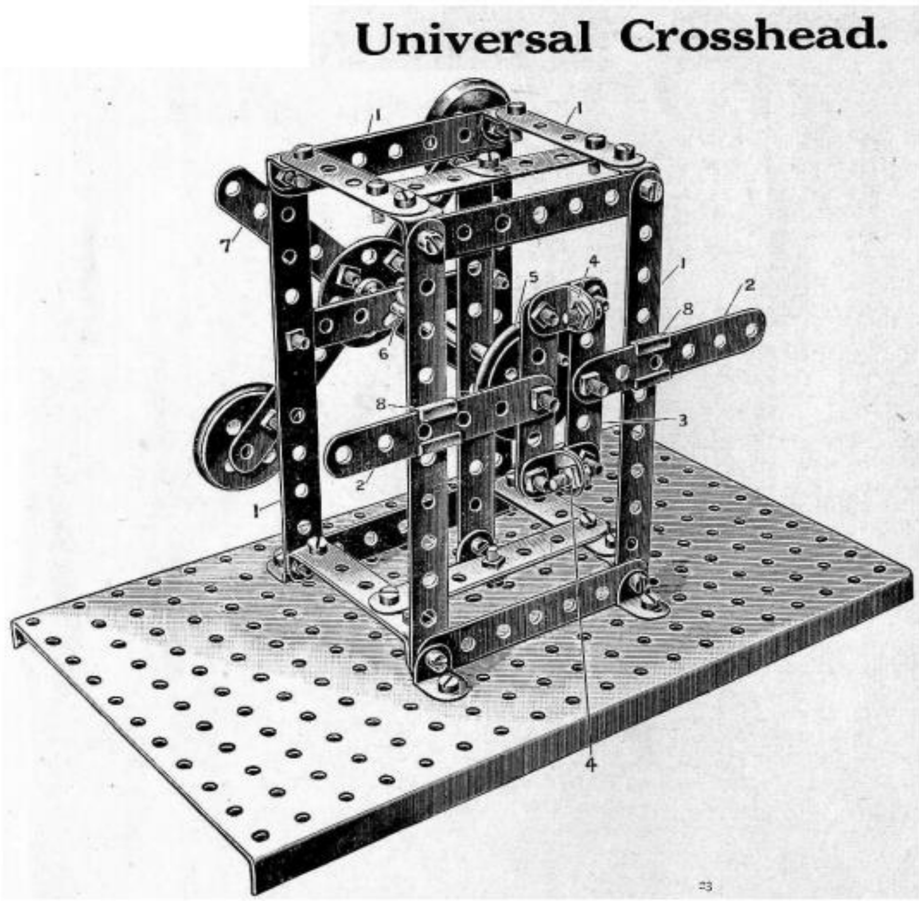

Figure 1.7: The 'Universal Crosshead' was one of the more scientific and engineering objects that could be created using the Hornby System of Mechanical Demonstration.
(Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-12).

[124] The Hornby System of Mechanical Demonstration Manual, 1913, pp. 20-25, https://www.meccanoindex.co.uk/Mmanuals/Theme/Manuals/HSMD.pdf [accessed 21 March 2016].
[125] Meccano Instructions Manual, 1910, p. 80, https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-12 [accessed 20 March 2016].

These sets also contained plans for models that teachers could use to explain gear trains, pulleys, levers, and epicycloidal gears.[126] The more scientific models in this demonstration system resulted in these types of models no longer being described as toys in the subsequent Meccano manuals. Instead, they were described as something that 'Engineers and architects use for designing models and inventing movements. Professors and teachers in technical schools use it to demonstrate mechanical principles to their students.'[127] Therefore, the 'elementary fundamentals of mechanics and mechanical science' that these school sets were designed to impart was incorporated into the main Meccano sets and manuals along with some of the same models. Although Hornby eventually discontinued the demonstration sets due to a low take-up in schools, they had shifted Meccano away from being simply an educational toy, turning it into an object that supported a boy's formal science and engineering education both inside and outside of schools.

This change in Meccano was reflected in the signifiers used in the marketing materials with Meccano sets described as:

> The Meccano system of interchangeable standard parts besides being an admirable system of mechanical toy construction also lends itself to the construction of many models for use in demonstrating scientific principles in the classroom.[128]

Two further examples include a newspaper advert from 1908 and a shop display card from 1910. The 1908 advert emphasises that Meccano is a toy, listing the various models that a user can build, in contrast to the 1910 shop display card, which features a smartly-dressed

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[126] The Hornby System of Mechanical Demonstration Manual, 1913, pp. 20-25, https://www.meccanoindex.co.uk/Mmanuals/Theme/Manuals/HSMD.pdf [accessed 21 March 2016].
[127] Meccano Instructions Manual, 1916, https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-14-16.pdf [accessed 20 March 2016].
[128] F. Hornby, 'Meccano Outfits with Electric Motors,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 4.

‘professorial’ father-figure and a middle-class boy dressed in a sailor’s suit constructing a crane (see figure 1.8a and 1.8b).

Figure 1.8a: An image reproduced from a 1910 Meccano advert. Note the emphasis on Meccano as a toy. (Image reproduced from https://www.alamy.com/stock-photo/1900s-uk-century-magazine-advert.html).

These changes alongside the inclusion of the ‘professorial’ father-figure signified to parents that Meccano was more than a toy, and that it had a formal educational value. These signs would have also encouraged interactions between boys and their fathers, who became increasingly prominent after the creation of the *Meccano Magazine* in 1916. Their development in the magazine reflects how Meccano gradually changed from an education toy to a training tool for would-be engineers.

Figure 1.8b: An image reproduced from a shop display card from 1910. Note the increased emphasis on the older suited gentleman as the dad for the Meccano boy. (Image reproduced with permission of R. Marriott, Meccano (Shire Publications, 2016)).

The shift from toy to training tool for would-be engineers features in the very first issues of the *Meccano Magazine* and the Meccano sets that it advertised. Compared to the original Mechanics Made Easy sets that had 17 distinct pieces, the 1916 Meccano sets had 65 distinct pieces, while the number of Meccano models in instruction manuals increased from 33 to 133. The majority of these new models (including Hooke's Coupling) were reproductions of the same scientific apparatuses that had featured in the *Hornby System of Mechanical Demonstration* in schools. These newer models were vastly more complex than those designed for users before 1908 (see figures 1.9a and 1.9b).

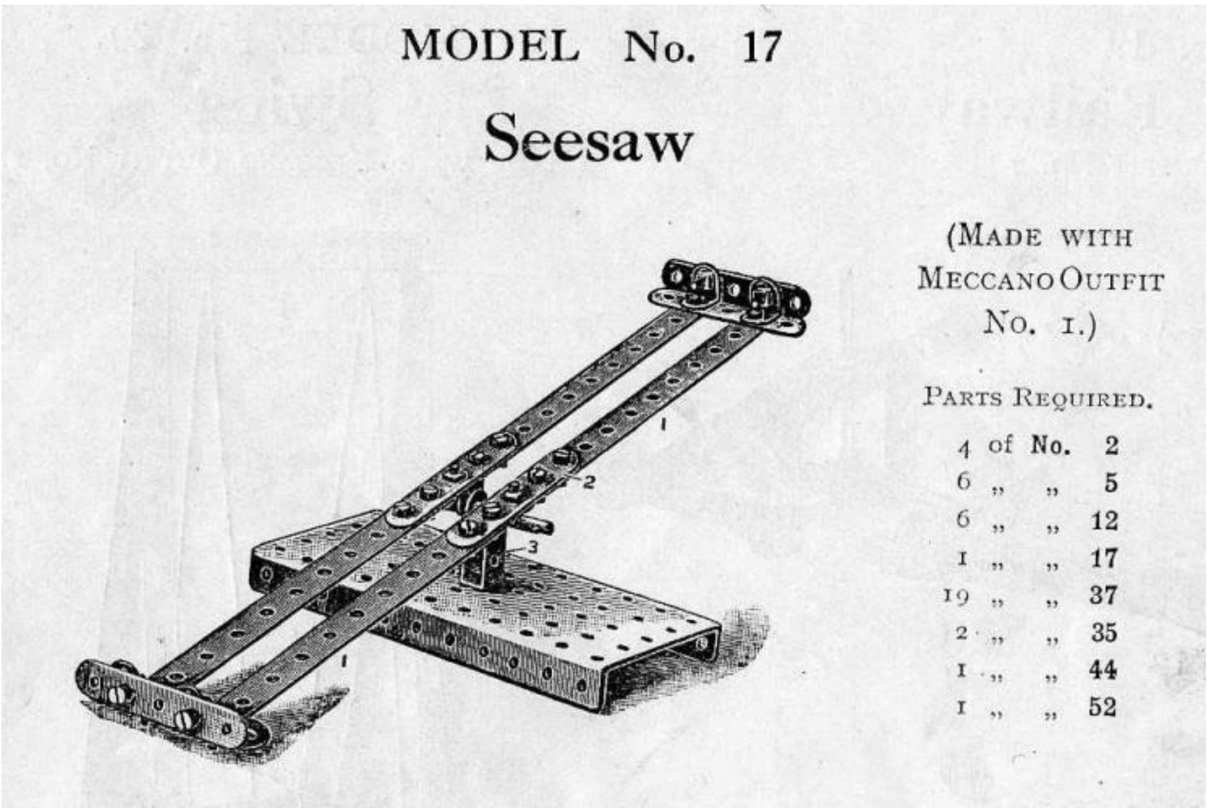

Figure 1.9a: An image of the 'Seesaw' model included in the toy model part of the 1916 Meccano Instruction Manual. (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-14-16.pdf).

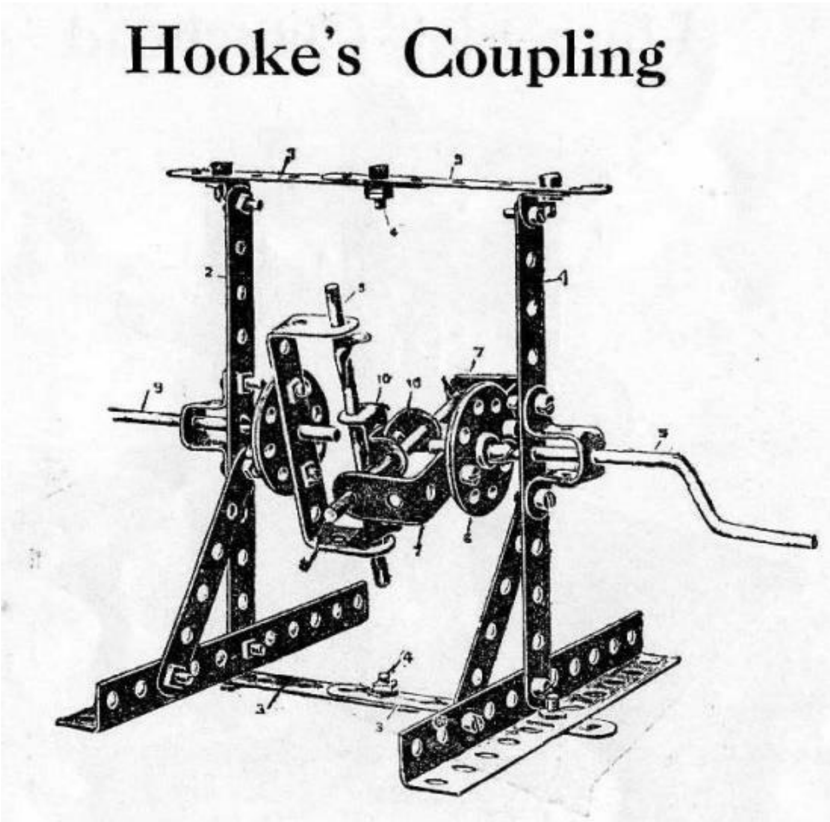

Figure 1.9b: An image of Hooke's Coupling, which was one of the more scientific models added in this issue that had directly been from the Hornby System of Mechanical Demonstration.
(Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-14-16.pdf).

The instruction manuals that accompanied these sets told readers that the newer models had been 'of the very greatest use to students who sought the main elementary fundamentals of mechanics and mechanical science,' and that they would also 'prove both useful and instructive to those who appreciated Meccano simply for the fun and pleasure which they derive from it.'[129] The inclusion of these two models in the same manual demonstrates that in 1916, Meccano was intended to be both an educational toy and a training tool for the Meccano boys who wanted (or whose parents wanted them) to become engineers who understood 'the main elementary fundamentals of mechanics and mechanical science.'[130]

[129] Meccano Instructions Manual, 1916, https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-14-16.pdf [accessed 20 March 2016]).
[130] Patent No. 587-1901, F. Hornby, 'Improvements in Toy or Educational Devices for Children and Young People,' (9 January, 1901), p. 1; and Meccano Instructions Manual, 1916, https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-14-16.pdf [accessed 20 March 2016]).

4. The *Meccano Magazine* and Meccano: A Training Tool for Would-Be Engineers

Historian Peter Bowler describes in '*Meccano Magazine:* Boys' Toys and the Popularisation of Science in Early Twentieth-Century Britain' (2018) that the *Meccano Magazine* as a 'short pamphlet devoted solely to material related to the construction set.'[131] While his statement corresponds to some aspects of the early issues, the reality of how the magazine developed and was used to change and regulate Meccano is much more complicated. Figure 1.10 is a table that demonstrates how the front cover themes of the *Meccano Magazine* changed before the Second World War. The colours in the table correspond to the different editors, with green denoting Hornby, yellow representing Hawks, and red corresponding to McCormick. This section will focus on the initial period in this table, analysing how Meccano was changed from toy to a training tool for would-be engineers. The effect of Hawks' editorship in changing Meccano into an aspirational emblem of fan-participation in international science and engineering is discussed in the following section.

Date	No. of Issues	Front Cover Theme (%)				
		Toy	Meccano Engineering Models	Real-World Engineering Projects	International Adventure	No Clear Theme
1916-1921	21	66	29	5	0	0
1921-1922	14	14	45	7	0	34
1922-1929	78	13	0	66	21	0
1930-1935	72	0	0	81	19	0
1936-1939	48	0	0	90	10	0

Figure 1.10: A table demonstrating a quantitative analysis of how the cover themes of the *Meccano Magazine* changed from the initial issues in 1916 to the beginning of the Second World War. The green row represents Frank Hornby's tenure, the yellow Ellison Hawks', and the third was after he resigned in 1935, when the editorship of the magazine passed to W. H. McCormick. (Data collated from the *Meccano Magazine*).

[131] P. Bowler, '*Meccano Magazine:* Boys' Toys and the Popularisation of Science in Early Twentieth-Century Britain,' *British Journal for the History of Science: Themes*, Vol. 3, (2018), p. 129.

Hornby created, edited, and published the first issue of the *Meccano Magazine* in September 1916. The by-line of the magazine throughout his tenure was '*To Help Meccano Boys To Have More Fun Than Other Boys*,' which emphasised that Meccano was a 'Boy's Toy.' However, the very first editorial of the new four-page publication reflected the dual purpose of Meccano he had created, as an educational toy and a training tool for would-be engineers. Hornby used it to echo the playful elements of the early Mechanics Made Easy sets and the more scientific models that had begun to be included in Meccano publications after the development of the *Hornby System of Mechanical Demonstration*. He spoke directly to the reader, asking that they: 'Write to the Editor as often as you like; he is just a grown-up boy with a lot of experience, and he knows how boys feel about things, and how to help them out of their difficulties.'[132] Hornby's self-described status as a 'grown-up boy' positioned him as the ideal outcome of the emergent Meccano boy user; someone who, through the same 'persevering application' that was required to construct complex models with Meccano, had become a successful, affluent man (echoing Smiles' self-help rhetoric).

The second article in the magazine was aimed more at the parents of the boys. Hornby used it to reinforce a father's expectations of their role in helping their (newly titled) 'Meccano boy' to consume Meccano. Titled '"Dad,"' it described the different names that Meccano boys might call their fathers. These included 'Father when he has money; Papa when he teaches Sunday School; and Pa when he shops with mother; but when he buys us Meccano and gives us a hand with the models till his fingers ache...we call him "Dad."'[133] The progression of Father, Papa, and Pa represented increasingly informal ways of referring to a male parent, before finishing with "Dad" (the least formal title that featured commonly as

[132] F. Hornby, 'Our First Number,' *Meccano Magazine*, Vol. I, No. 1, (September, 1916), p. 1.
[133] F. Hornby, 'The Premier Toy,' *Meccano Magazine*, Vol. I, No. 1, (September, 1916), p. 4.

part of a child's lexicon).[134] By personifying the attributes of "Dad" as someone who bought their sons the sets they needed to become Meccano boys, Hornby implicitly guided the manners and behaviours of both the Meccano boys and their parents. While the concepts and ideas that the Meccano boy and his dad were used to signify in the *Meccano Magazine* changed considerably over the coming years, the responsibility of the 'Dad' to support the Meccano boy would go on to play a significant role in the development of the Meccanomen movement after 1965.[135]

The success and popularity of Meccano in its second decade led to the development of similar competitor products that embraced the philosophy of self-improvement through construction. These included the German-produced Märklin (licensed to sell Meccano products from 1914), Tinkertoys (invented in 1914), and Lincoln Logs (invented in 1916). While each of these offered competition to Meccano products, a more significant challenge came from the publication of books similar to Stout's *The Boy's Book of Mechanical Models* (1917). Stout's book contained a similar philosophy to that of Hornby and other competitor products that '...[giving] the real boy some tools and a workshop, half the problem of bringing up the next generation is solved.' However, in contrast to Hornby, he asserted that boys did not need a formal medium of construction – such as Meccano – to build these models and

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[134] OED results for:
Father:
http://www.oed.com.chain.kent.ac.uk/view/Entry/68498?rskey=jmfnaf&result=1#eid;
Papa:
http://www.oed.com.chain.kent.ac.uk/view/Entry/137082?rskey=rLPEPg&result=2&isAdvanced=false#eid;
Pa:
http://www.oed.com.chain.kent.ac.uk/view/Entry/135753?rskey=mHxcST&result=12&isAdvanced=false#eid;
and Dad:
http://www.oed.com.chain.kent.ac.uk/view/Entry/46813?rskey=kJFMdQ&result=1&isAdvanced=false#eid
[accessed 25 June 2018].

[135] The movement was developed by a group of fathers and grown-up Meccano boys who felt that the Meccano outfits and how they were presented in the *Meccano Magazine* had changed in comparison to Hornby's initial vision that they grew up with. Chapters Five and Six will explore how this group of grown-up Meccano boys created an 'alternative' version of Meccano and publications based on their nostalgia to return to a 'golden age' they believed 'Hornby would have wanted.'

improve their mechanical education. Instead, he asserted that the self-improvement that could be achieved through playing with construction toys could also be accessed with 'things picked up around the house, at no expense to the maker,' including the scraps needed to produce his 'German "Thur-Zither"' object (see figure 1.11).[136] Stout's alternative approach presented a challenge to Meccano and Hornby's desire for it to be the primary 'boy's toy' consumed by 'Meccano boys' and their dads to have fun and learn engineering skills.

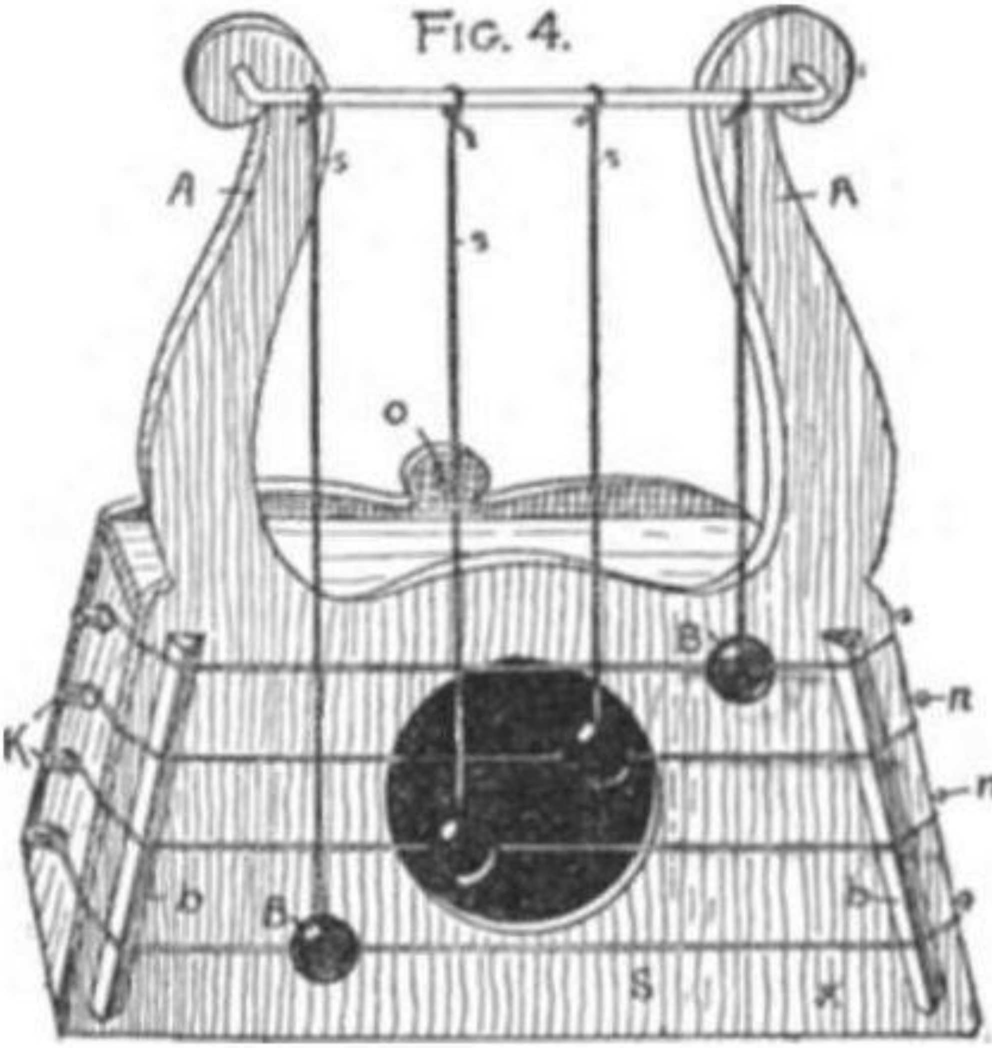

Figure 1.11 An image of the 'Thur-Zither' or 'Door Musicbox' from Stout's book of mechanical models that encouraged boys to build objects with items they could find around the house. (Image reproduced from W. B. Stout, *The Boy's Book of Mechanical Models* (Little Brown, 1917)).

[136] W. B. Stout, *The Boy's Book of Mechanical Models* (Little Brown, 1917), p. 2.

Hornby responded to these alternatives by redeveloping Meccano, inserting a page into instruction manuals from 1917 that told readers ‘It is important to remember that when a boy is playing with Meccano, he is using engineering parts in miniature and that these parts act precisely the same way as the corresponding engineering elements would do in actual practice.’ Alongside this statement, Hornby also told users that in comparison to Meccano, ‘No other system of model construction could, therefore, be correct. Other toys which attempt the same object by other methods must avail themselves of other constructive elements which are not correct engineering elements.’ He also used this page to set Meccano apart from these alternative products and approaches by asserting that the self-improvement skills they could teach users were flawed as they ‘…are merely toys, and nothing else, and [the boy’s] mind, as regards proper mechanical construction and methods, is distorted instead of instructed.’ Hornby used the final words on this new page to speak directly to the parents of Meccano boys, telling them that if they use non-Meccano products, their son would ‘learn…wrong principles, and when his ambition tempts him to invent or construct more elaborate models, he will be stopped by the deficiencies of his non-mechanical system.’[137] Hornby’s choice of language with this insert highlights how he had changed Meccano from a toy that ‘enhanced a user’s mechanical education’ in 1901, into something he described as the only medium through which boys could learn ‘proper’ mechanical and scientific principles. The assertion that the engineering principles provided by alternatives were ‘wrong’ compared to Meccano also had the effect of increasing the rhetoric that it was a training tool for would-be engineers, rather than simply an educational toy.

[137] Meccano Instructions Manual, 1914, https://www.meccanoindex.co.uk/Mmanuals/1908/Manuals/1-6-14.pdf [accessed 20 March 2016].

These two versions of the toy were also on display in the third issue of the *Meccano Magazine*, published on March 1917. Hornby used the magazine to develop the Meccano boy character from one that played with Meccano as a toy, to one that could also use it to learn formal mechanical and education skills during his teenage years. The three articles in this issue of the magazine demarcated the characteristics that Meccano boys were expected to embody at different ages. The reader was told that the author of the first article 'Meccano as a Toy' was an eleven-year-old boy, R. H. Cobbold, while the other two articles 'Meccano as a Help to the Study of Engineering' and 'Meccano as a Help to Engineering,' were written by older Meccano boys, D. Nash, and H. Beard, sixteen and fourteen years old respectively. Cobbold's article opened with a description of Meccano: 'There are toys *and* toys. Some are only toys. Meccano is a toy, but a jolly good one. It is never a waste of time to play with Meccano. You can begin when you are quite young and go on till you are quite an old boy.'[138] This was in direct contrast to Stout's approach, which told boys that they could construct objects out of any household items they could get their hands on ('take some cigar-box wood and make a mechanical duck.')[139] Cobbold then directly compared Meccano to the alternative construction toys that were growing in popularity at the time. Using language that was similar to that found in earlier Meccano adverts, he told readers that:

> Meccano does not break as other toys do, and it is not nearly so expensive as many useless things which are only toys. It must be nearly worth its weight in gold. In Meccano, you make your own toys; you make them work, too, especially if you have a motor […] this is why it lasts so long. You have never finished.

[138] R. H. Cobbold, 'Meccano as a Toy,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 3.
[139] W. B. Stout, *The Boy's Book of Mechanical Models* (Little Brown, 1917), p. 3;

The purpose of this language in Cobbold's article would have been to encourage Meccano boys to ask their parents to purchase further outfits and interval sets, and reassure their fathers that Meccano was a toy that was fun, educational, and value for money.

Cobbold's article then addressed the two versions of Meccano that Hornby had cultivated with a poem, which provided a blueprint of characteristics for how all young Meccano boys should be when they use Meccano as a toy (intelligent, quiet, respectful, and middle-class):

> Of all the fascinating toys
> That kind folk give deserving boys,
> This is the one that never cloys
> And never anyone annoys;
> The time it usefully employs,
> And ne'er engenders any noise
> It happily the hump destroys,
> And fosters educative joys;
> Each faculty it well deploys,
> And keeps the mind in equipoise;
> A young mechanic nought enjoys
> So much as this, the best of toys.

The language in this poem stands out, both for its complexity, and similarity to the way that Hornby had previously described Meccano. While I would not suggest that the character of Cobbold was a fabrication for the magazine, I suspect that Hornby may have had a direct hand in editing the article. This assertion is made based on the language used and the way the article perfectly captured the sentiments for Meccano that Hornby had also created and presented in other marketing materials and instruction manuals. The concluding paragraph of Cobbold's article reaffirmed the characteristics of Meccano boys who used it as a toy. He told users:

> "Toy" rhymes with "boy" very happily; no two things go so well together. Also, noise rhymes with "boys"; but there is this about Meccano – it is the most silent of toys. You can go on working so quietly that people do not know that you are in the room with them and they sometimes forget to say that it is time to go to bed…You do not know you are learning things, but you are all the time. Not many toys do that.

His words served a dual purpose, telling younger users that to be a Meccano boy they had to be quiet, while also reinforcing to parents that playing with Meccano sets at a young age was crucial to their children's ability to learn basic mechanical principles 'all the time.'[140]

Therefore, similar to Barthes' 'Paris Match' front cover, the inclusion of Cobbold's picture alongside his essay signified the qualities and attributes described in his article to other similar age Meccano boys. The image of Cobbold (11) as a young boy in school uniform sat alongside a picture of D. Nash (16), and an article by H. Beard (14), whose articles described Meccano as a training tool for would-be engineers rather than as a toy. The image of Nash as a teenage boy dressed in a suit would have had the effect of signifying that these Meccano attributes were for older users (see figure 1.12).

[140] R. H. Cobbold, 'Meccano as a Toy,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 2.

Figure 1.12: The image on the left is the picture of Ronald H. Cobbold (dressed in similar clothes to the boy from the 1908 instruction manual), while the picture on the right is David J. Nash (dressed in a suit similar to the images of older Meccano boys from 1910 and later in 1932). (Images reproduced from *Meccano Magazine*, Vol. I, No. 3, (March, 1917)).

Nash's article 'Meccano as a Help to the Study of Engineering' told readers that Meccano was a training tool that had directly assisted him in attaining his school qualifications and eventual apprenticeship at an engineering firm. He explained that 'On commencing studies, I found that my work in the mechanical department had been lightened considerably by Meccano,' before referencing a series of Meccano models that he believed had given him these engineering skills. These included: 'Mechanical Advantage,' 'Velocity Ratios,' 'Gearing Mechanisms,' and 'Belt and Chain Driven Pulleys' models, which had been introduced as a result of *The Hornby System of Mechanical Demonstration*. In fact, the engineering skills listed in Nash's articles were exact copies from those that had been introduced into instruction manuals in the previous year, suggesting that once again Hornby had a hand in the article. The skills and models listed in his article were an equivalent to Cobbold's descriptions of Meccano as a toy, except that instead of reaffirming the status of Meccano as a toy, he told readers that boys like him had 'scarcely known what engineering was before Frank Hornby had invented Meccano,' but that 'nowadays…hundreds and even thousands of boys had practical experience in the line of mechanical engineering, and this is the result of Meccano.' He then told readers that 'It will be realised that the principles of Meccano are true engineering principles and that when a boy is enjoying himself with Meccano, he is learning something of practical use and great importance.'[141]

Similar to Nash, Beard's article, 'Meccano as a Help to Engineering,' also presented Meccano as a training tool rather than an educational toy, telling readers that his apprenticeship at an engineering firm had been made easier by his previous use of Meccano. He described how 'The firm…could see that [I] had it at [my] fingers' end.' While Beard does not state what 'it' was at his fingers end, the rest of his essay suggests that he was referring to practical, real-world engineering skills that he had learned with Meccano. His allusion to skills at his 'fingers' end' also echoes Smiles' philosophy that the fingers were the primary inlet for mechanical instruction ('No book knowledge can avail for that purpose.')[142] Beard then told readers that the firm felt that his skill level was so high that he must have previously studied engineering books, and that they were surprised to learn that he had only used Meccano. He emphasised that Meccano was a training tool for would-be engineers by relaying the feedback he received from the firm to readers: 'Well if yours is a case of working with Meccano, it must be a grand thing for a boy to study.' Beard's concluding paragraph told the reader, 'I have three other brothers who are all keen on Meccano, and I can say honestly

[141] D. J. Nash, 'Meccano as a Help to the Study of Engineering,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 2.
[142] S. Smiles (ed.), *James Nasmyth: An Autobiography* (London, 1883), p. 97.

that if we turn out a family of engineers, we shall owe it all to your splendid gift of Meccano.'[143]

These articles and excerpts help to establish the different ways Hornby used the marketing materials, instruction manuals, and *Meccano Magazine* to make the standardised pieces of Meccano represent alternative things for different groups of users. What is most striking about the attributes and the signifiers attached to the two versions of Meccano as an educational toy and as a tool for would-be engineers is that despite their differences, they both refer to the same physical pieces of Meccano, which had remained unchanged since 1901. The existence of these two versions of Meccano and two groups of Meccano boys highlight the problems with the Kroto's synchronic perspective and previous historical analyses of Meccano, which are based on the 'particular solidarity' that because it was an unchanged physical object, it only had a single meaning and application among a homogenous group of users.

Hornby also used the 'Our Mail Bag' section to influence and regulate how different groups of users engaged with the different versions of Meccano. A young reader wrote to Hornby in 1917 to tell him that 'The *Meccano Magazine* is just what is needed to make all Meccano boys feel like a sort of brotherhood, all interested in real good means of learning and having ripping fun.'[144] Hornby's response 'We could not have expressed it better ourselves' was a confirmation that for this young reader, Meccano was intended to be a toy. However, in another letter in the same issue, Hornby outlined the transition for how Meccano boys should use Meccano as they grew up, telling another young user, 'Don't worry because you are only a little Meccano boy. All little Meccano boys grow into big useful Meccano boys.'

[143] H. H. Beard, 'Meccano as a Help to Engineering,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 2.
[144] J. B. H. Barnard Castle to F. Hornby, 'Our Mail Bag,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 4.

These two letters demonstrate how Hornby cultivated two versions of Meccano as distinct things, a separation that is evident in his response to a third letter from a concerned reader who felt his use of Meccano was 'kiddish.' Hornby replied:

> Why should it seem "kiddish" to use Meccano at your age? Men of eminence are working with it and playing with it every day that goes by. The Meccano boys who are now fighting for their country in a goodly army, and like yourself, many of them owe their knowledge of mechanics to their hobby.[145]

The separation of men and boys in this letter further establish the two versions of Meccano he had developed. These three letters also demonstrate how Hornby used the 'Our Mail Bag' section to regulate how Meccano boys of different ages should engage with and understand Meccano.

Hornby also used the feature to reaffirm the relationship between Meccano and mechanical and scientific principles. In response to a letter from a university engineering professor, he wrote, 'We receive many letters from gentlemen in your profession, telling us of the help which Meccano has been to them. We hope you will be interested in the Scientific Competition announced in this issue.'[146] The competition built on the popularity and successful use of Meccano to build scientific models in schools during the previous decade, and called on 'our scientific young friends' to construct 'models suitable for scientific demonstrations,' and submit them to win prizes.[147] Hornby's responses to letters such as this, alongside the development of the scientific competition, helped to signify to older users and

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[145] F. Hornby to Gunner D. W. T. Catterick, 'Our Mail Bag,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 4.
[146] F. Hornby to G. H. Cambs, 'Our Mail Bag,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 4.
[147] F. Hornby, 'A New Meccano Scientific Competition,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 3.

their parents that Meccano was not just a toy, but a tool that could help them to become engineers.

5. Ellison Hawks and the 'Eminent Engineers': Raising the Aspirations of the Meccano Boys

Frank Hornby's decision to establish the 'Meccano Guild: A Fellowship of Meccano Boys' in 1919 is another demonstration of how he had changed Meccano since inventing it as Mechanics Made Easy in 1901. He wrote that he created the Guild in response to 'the million boys in Great Britain [who] derive their greatest indoor pleasure from Meccano.'[148] In contrast to the synchronic, conventional public history of Meccano, the three objects of the new Guild reflect the two versions of Meccano that he had developed since 1901:

(a) To make every boy's life brighter and happier.

(b) To foster clean-mindedness, truthfulness, ambition, and initiative in boys.

(c) To encourage boys in the pursuit of their studies and hobbies, and especially in the development of their knowledge of mechanical and engineering principles.[149]

The first object reflects that Meccano was an object that could be used by both younger and older Meccano boys. The reference to 'clean-mindedness, truthfulness, ambition, and initiative' in the second object reflects the principles of Samuel Smiles' self-help literature that originally inspired Hornby to patent Mechanics Made Easy as a children's educational toy. The final object reflects how Meccano was also a training tool for older users that supported their formal engineering education as would-be engineers.

Between 1916 and 1919, the number of distinct Meccano pieces grew again from 65 to 148. This led to an expansion in the variety of models that were featured in Meccano instruction manuals, from 133 to 343. An analysis of these additions highlights that these new

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[148] There are no sources to support this claim of 'a million boys.' The readership of the magazine in this period was nearer 30,000, while the sales of sets was about double this figure per year.
[149] F. Hornby, 'The Meccano Guild: A Fellowship of Meccano Boys,' *Meccano Magazine*, Vol. I, No. 10, (September, 1919), p. 2

models ranged from the playful and straightforward Luggage Cart (Model No.4) to the scientific and more complex Loom (Model No. 307), which helps to demonstrate how the two versions of Meccano continued to be developed and differentiated by Hornby in the same instruction manuals (see figure 1.13).

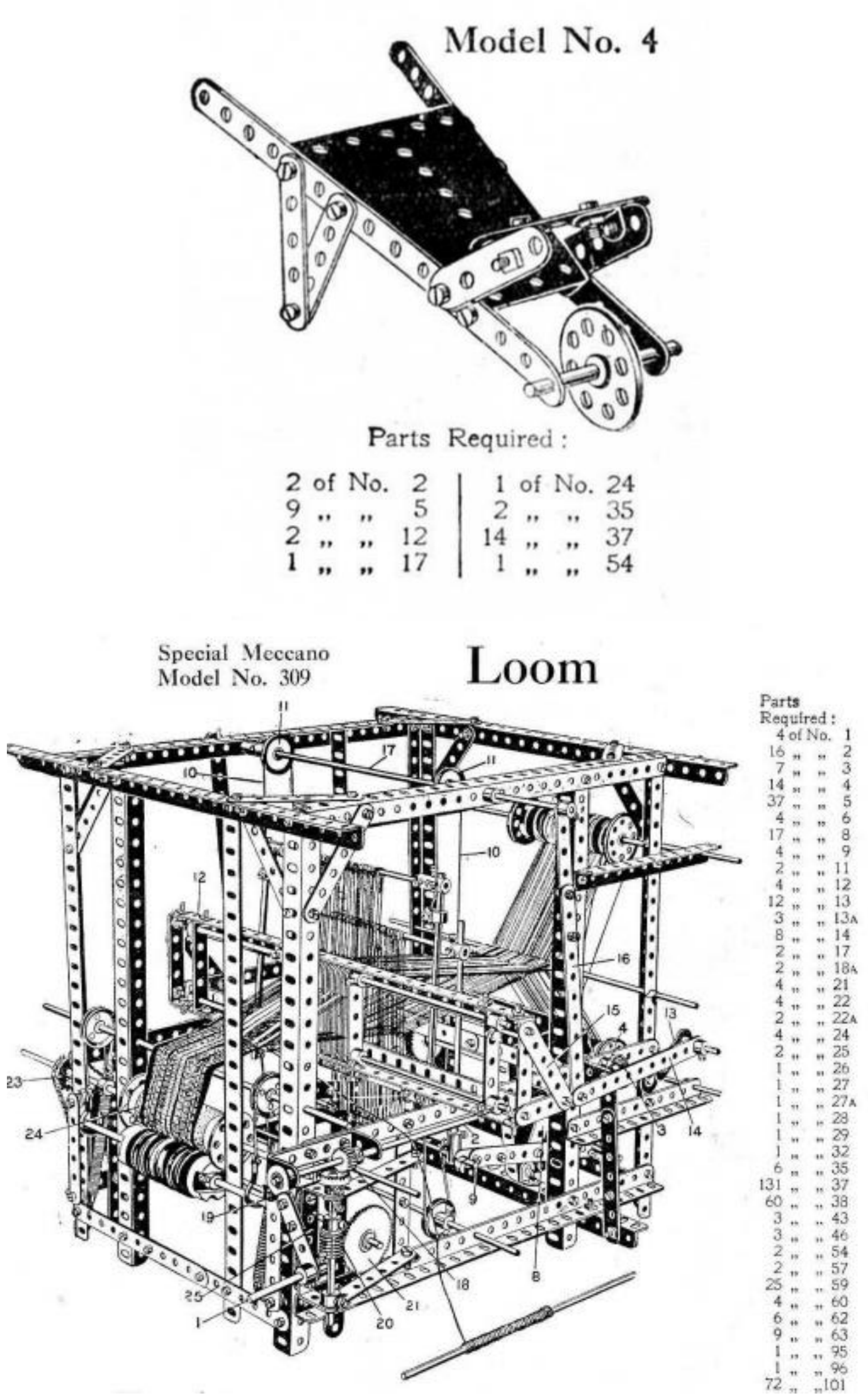

Figure 1.13: The top image of the 'Luggage Cart' model and the bottom image of the 'Loom' are two examples of the contrasting models that were added to Meccano instruction manuals from 1921.
(Images reproduced from https://www.meccanoindex.co.uk/Mmanuals/1916/Manuals/1-21-10.pdf).

However, Hornby's involvement with Meccano decreased around the same time as these instructions manuals were released. Part of the reason for this was that he began to develop Dinky Toys and the Hornby Dublo model railway system, before later becoming a Conservative MP for the Everton constituency in the 1931 General Election.[150] He was replaced as editor of the *Meccano Magazine* in 1921 by Ellison Hawks. In Hornby's absence, Hawks transformed Meccano into a global brand that was sold across the British Empire in over twelve languages during the later years of the 1920s.[151] He also changed the content and style of the *Meccano Magazine* from a four-page publication that cost a penny in 1921, to a forty-eight publication that cost sixpence in December 1923.[152]

Hawks' new version of Meccano led to it being marketed less as a toy or as a training tool for would-be engineers. Alongside the changes made to the *Meccano Magazine*, the Meccano instruction booklets were also changed, with the more playful and straightforward Meccano models being replaced with more complicated models in the second half of the 1920s. The models removed included the 'Trolley Car' (in 1925), the 'Luggage Barrow' (in 1926), and the 'Clothes Horse' (in 1927). Increasingly, the models added to replace them represented real-world engineering objects, including the 'Steam Shovel' (in 1924), the 'Aeroplane' (in 1926), and the 'Mechanical Motor Lorry' (in 1927).[153] This new direction is noticeable in the March 1922 magazine editorial, in which he developed on the idea that Meccano was 'primarily engineering in miniature,' describing how 'parts of the system represent real engineering units and thus lend themselves more particularly to the building

[150] A. McReavy, *The Toy Story: The Life and Times of Inventor Frank Hornby* (Ebury Press, 2002); and M. P. Gould, *Frank Hornby: The Boy Who Made $1,000,000 With a Toy* (Fredonia Books, 2004).
[151] E. Hawks, 'A Backward Glance,' *Meccano Magazine*, Vol. LII, No. 7, (July 1967), p. 27.
[152] *Meccano Magazine*, Vol. VIII, No 12, (December 1923).
[153] Various Meccano Instructions Manuals, 1924-1927, https://www.meccanoindex.co.uk/Mmanuals/1922/Intro.php?id=1553687355 [accessed 20 March 2016].

of models of engineering structures.'[154] Alongside this push to establish a greater sense of realism, Hawks changed the content and style of Meccano instructions manuals, reducing the number of Meccano cranes, planes, and trains in favour of more complicated scientific and engineering objects.[155] This shift was also reflected in his decision to rename these manuals as 'Meccano: Engineering for Boys,' alongside the introduction of inspiring stories of engineers and international adventure(r)s to the magazine. Hawks' changes represented a new way of demonstrating Meccano in a real-world context, which told readers that through using Meccano, they could aspire to, and participate in the world of science and engineering.[156]

These changes were designed to tell all users that they could aspire to the more complex models that featured, the reality is that few – except for those from wealthy families – could have participated in building them at home. This was because increasingly, the models presented in the *Meccano Magazine* tended to require at least a No. 7 set, which cost 370 shillings in 1927 (£700 in 2017).[157] Based on Meccano's financial statements from the time, the most popular sets sold were the smaller No. 00, 0, 1, or 2 sets, which cost between 3 shillings and 6 pence (£7 in 2017), and 15 shillings (£30 in 2017).[158] This meant that for the majority of those who read the magazine, the high costs of the larger sets made physically building the larger models that featured both on the cover and inside the *Meccano Magazine* out of reach. Despite this, Hawks increased the prevalence of these larger objects in the

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[154] E. Hawks, 'Editorial,' *Meccano Magazine*, Vol. VII, No. 3, (March, 1922), p. 1.
[155] Melanie Keene's article '"Every Boy & Girl a Scientist:" Instruments for Children in Interwar Britain,' *Isis*, Vol. 98 (2), (2007) alludes to Hawks' role in helping to develop Construments sets in 1930. The similarity between these sets of Meccano and Construments are discussed further below in the following section.
[156] The advertisements featured in the *Meccano Magazine*, Vol. VII, No. 3, (March, 1922), p. 6; and *Meccano Magazine*, Vol. VII, No. 10, (October, 1922), p. 7.
[157] Currency converted using http://www.nationalarchives.gov.uk/currency-converter/ [accessed 18 February 2020].
[158] Various Meccano Financial Statements and Annual Reports, 1920-1980, B/ME/6/1-6. Currency converted using http://www.nationalarchives.gov.uk/currency-converter/ [accessed 18 February 2020].

magazine, which still served to raise aspirations by giving users the ability to both read about and use the same pieces of Meccano that featured in complex, real-world machines. While it may have been possible that as members of these Meccano clubs they pooled resources to purchase larger sets, there is no record of this in the *Meccano Magazine*. Instead, many issues describe how the Meccano Guilds functioned as spaces for boys to bring their own models to demonstrate to each other, as part of a wider set of activities, rather than a group effort to build the larger models.[159] One method that allowed Hawks to ensure these objects remained aspirational for all users was through the process of 'Meccano-fication,' whereby objects and models were purposely redrawn and simplified to make them appear to be within reach of the Meccano boys.

The yellow rows in figure 1.10 help to more broadly demonstrate how Hawks changed the themes of the *Meccano Magazine*. They highlight that Hawks used the magazine during his tenure (in yellow) to reflect and support his new version of Meccano as an aspirational emblem of fan-participation in international science and engineering. The table establishes that Hawks reduced the appearances of Meccano boys – that had featured on 85% of the front covers during Hornby's editorship – to less than 14% between 1922 and 1929. The reduction of the Meccano boys also led to a change in prominence of the character of their "dad." From being part of the family unit that had supported the Meccano boy in play, the father-figure was increasingly portrayed as a member of an industry that was actively engaging with a machine or engineering project as an 'eminent engineer'. This phrase was introduced and used as a catch-all phrase for many different professions in the *Meccano Magazine*, including in the May 1926 issue, where the phrase 'eminent engineers' is used to

[159] *Meccano Magazine*, Vol. XI, No. 5, (May, 1926), pp. 339-340.

refer to the men cleaning the train on the front cover.[160] Variations of this phrase also increasingly featured, most often in new sections on 'Lives of Famous Engineers' from 1922, and 'Famous Inventors' from 1923.[161] This work borrows from Hawks' approach and uses the phrase 'eminent engineer' as a label for the variety of isolated engineering and scientific characters that replaced the Meccano boy and father-figure in marketing materials, featuring on 39% of Hawks' 150 front covers after 1921.

The table also highlights the ways that Hawks changed the content of the magazine to reflect the increasingly international markets into which he expanded sales of Meccano. Throughout his tenure, less than 40% of the real-world engineering projects featured on the front cover were from the UK, with the other 60% comprised of international engineering objects and adventure(r)s. Nevertheless, the front cover of the *Meccano Magazine* continued to feature Meccano as both a toy and a tool for would-be engineers during the first year of Hawks' tenure. However, while the two young boys playing with the Meccano model dominate the March 1924 issue, the Meccano instruction manual behind them is open to an image of a crane that also features in the background image of a real-world dock. The April 1924 cover followed a similar pattern, featuring the Meccano boy and chassis (reprinted for the fourth time since 1916) in the centre of the image. However, for the first time, the image of the chassis also included references to 'The New Torque Converter,' despite the same image featuring on the front cover three times previously. This was as a result of Hawks introducing the torque converter into Meccano instruction manuals in the same year, signifying the increasingly real-world applications of the object (see figure 1.14).

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[160] E. Hawks, 'Cleaning the Giant Locomotive: The "Flying Scotsman's" Four Hours' Toilet,' *Meccano Magazine*, Vol. XI, No. 5, (May, 1926), pp. 290-292.

[161] 'Famous Engineers' first appeared in the *Meccano Magazine*, Vol. VII, No. 4, (April, 1922); and 'Famous Inventors' in *Meccano Magazine*, Vol. VIII, No. 3, (March, 1923). They both continued to sporadically appear until the mid-1930s.

Figure 1.14: The left image is from the March 1924 issue of the *Meccano Magazine*, while the image on the right is from the April 1924 issue. (Images reproduced from http://meccano.magazines.free.fr/index.htm).

Hawks replaced these images in the May 1924 issue of the magazine, opting instead to feature real-world industrial scenes, engineering projects, and from June 1925, an increase in international adventure content, in the form of the 'Swiss Mountain Railway' image (see figure 1.15).

Figure 1.15: The top-left image is from the newly-formatted *Meccano Magazine* issue from May 1924, demonstrating an example of real-world engineering. The top-right image from July 1924 is the first example of the inclusion of men on the front cover, engaging with the furnace in the centre of the image. The bottom image of the Swiss Railways from June 1925 is Hawks' first example of an internationally-themed cover.
(Images reproduced from http://meccano.magazines.free.fr/index.htm).

The June 1925 issue was also the first time that the subtitle ‘For Boys’ was removed from the front cover. These changes would have signified to users that Meccano was a toy through which they could participate in, and aspire to be part of, the complex engineering and international adventure(r)s on display. Hawks’ new version led to the replacement of articles that discussed Meccano as a toy, in favour of ones describing large engineering projects, machines, and adventure(r)s.[162] Therefore, while fewer users could directly participate in building these larger models due to cost, the creation of the ‘eminent engineer’ figure – who would go onto act as the main Meccano protagonist in subsequent issues, and replaced the Meccano boy and often manipulating the engineering objects on display – allowed them to participate in the more complex models on display, increasing their aspirations.

Hawks’ efforts to change Meccano into an aspirational emblem of fan-participation reflected the style of the popular science literature that he had also authored during this period. Hawks’ books told stories similar to those that featured in the *Meccano Magazine*, including heroic stories of international adventure(r)s and developing scientific technologies. His publications included:

The Microscope (New York, 1920)

The Romance and Reality of Astronomy (London, 1922)

The Romance and Reality of Radio (London, 1923)

Engineering For Boys (London, 1923)

Wonders of Speed (London, 1924)

[162] He reflected on this change in a short 1967 memoir, ‘A Backward Glance.’ The article provided a retrospective of his time with the magazine, which (at the time) was scheduled to be discontinued due to falling sales (it was later resurrected and discontinued twice more, before ceasing publication permanently in 1981 – more on this story in Chapter Five).[162] He stated that the ‘M.M. [commenced] to branch out to cover subjects that were of general interest.’ These more general interest articles included ‘The Story of Rubber,’ ‘The Story of our Daily Bread,’ and ‘Stamp Collecting,’ which became increasingly prevalent in the magazine in the later years of the 1920s.

Pioneers of Wireless (London, 1927)

The Book of Remarkable Machinery (London, 1928)

The Triumph of Man in Science and Invention (London, 1929)

The Book of Electrical Wonders (London, 1929)

The Wonders of Engineering (London, 1929)

The Romance of Transport (London, 1931)

The Romance of the Merchant Ship (London, 1931)[163]

The introduction of Hawks' book *The Microscope* (1920) states that it was written in response to a letter that he received from a 'young friend' John. Hawks wrote that the objects he had described – pollen, plant cells, and spider webs – could be seen by anyone 'fortunate' enough to own a microscope. He told John – and by extension the reader – that 'not only may you see these objects, but from the little I have told you about them, you will be able to understand them, to know something of their life-history and the part they play in Nature.'[164] This style in his publications was designed so that readers could see and understand these complex concepts, presenting them in an aspirational way to overcome the fact that many readers would not have been able to afford their own microscope. The subsequent chapters in the book present the microscope and its applications using aspirational language and images similar to those that would later feature in the *Meccano Magazine*, including real-world images of plates from microscopes used in research laboratories (see figure 1.16).

[163] A full reference of these books features in the bibliography of this chapter.
[164] E. Hawks, *The Microscope* (New York, 1920), p. 10

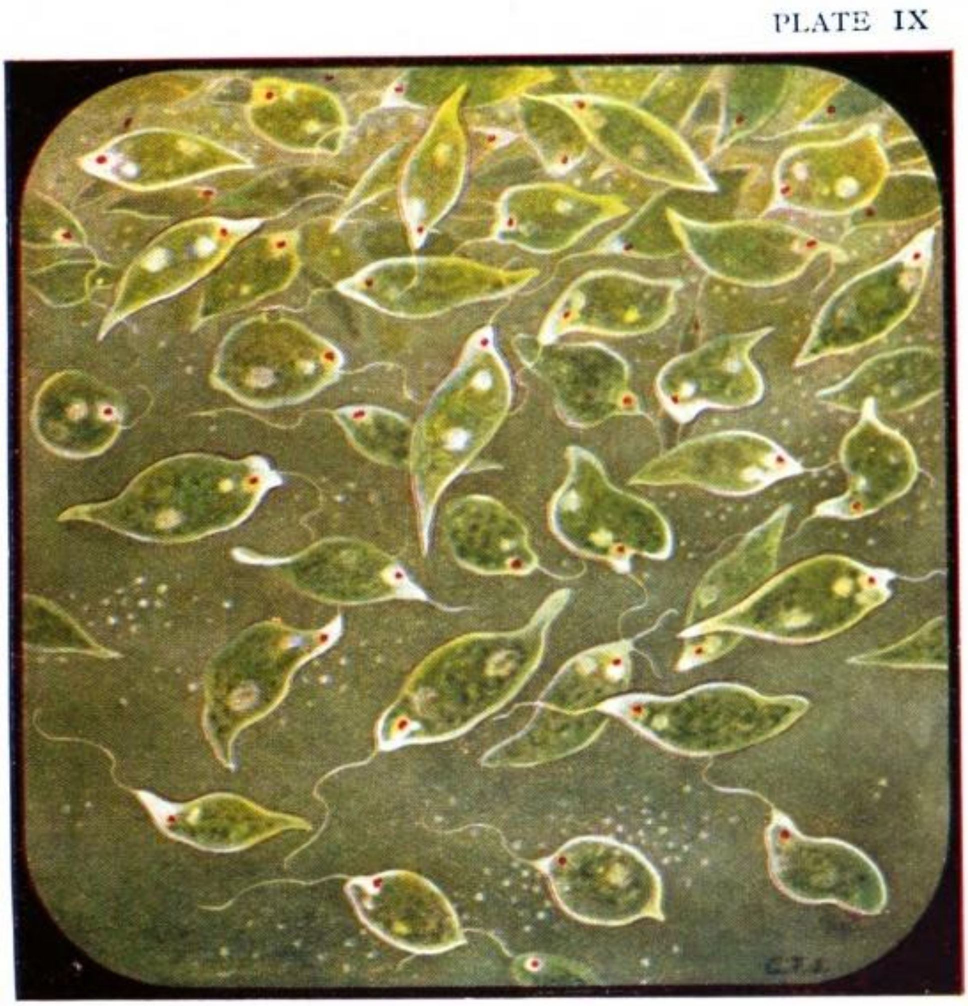

Figure 1.16: A water-colour painting of a plate from Ellison Hawks' *The Microscope*, displaying a swarm of *Euglena viridis* near the surface of a stagnant pond. (Image reproduced from Ellison Hawks, *The Microscope* (1920)).

These 'real-world' aspects of science and engineering Hawks' publications translated to the *Meccano Magazine* as heroic stories of inventors, adventure(r)s, and explorers, as well as engineering and scientific machines and concepts. These included articles on 'Giant Steam Shovels: That do the Work of 2000 Men,' together with serials based on the 'Lives of Famous Engineers.'[165] Perhaps the most obvious example of the changes Hawks made was in the reprinted version of Frank Hornby's serial 'The Life Story of Meccano,' which was first published in 1917. Despite no substantive changes to the text of the serial when it was republished in 1932, its title had been changed to 'The Life Story of Meccano: Romance of the

[165] E. Hawks, 'Giant Steam Shovels: That do the Work of 2000 Men,' and 'Lives of Famous Engineers' *Meccano Magazine*, Vol. IX, No. 1, (January 1924), pp. 1-28.

World's Greatest Toy.'[166] This edit confirms what has been established previously, that Hawks' authorship of these popular science books bled over into how he shaped and changed Meccano into an aspirational emblem of fan-participation in international science and engineering. The following section will build on this by considering the impact that Hawks' role as a Director at Construments had on his editorship of the *Meccano Magazine*.[167]

[166] F. Hornby, 'The Life Story of Meccano: Romance of the World's Greatest Toy,' *Meccano Magazine*, Vol. XVII. No. 1, (January, 1932).
[167] M. Keene, '"Every Boy & Girl a Scientist: Instruments for Children in Interwar Britain," *Isis*, Vol. 98 (2), (2007), pp. 268-274.

6. The Meccano Challenge!: From Aspiration and Expertise to Nationalism and British Engineering

Melanie Keene discusses the issue of aspiration-raising in her research into Construments sets in '"Every Boy & Girl a Scientist: Instruments for Children in Interwar Britain"' (2007). First released in 1932, Construments sets were similar to Meccano in that they provided users with a similar set of reduced tools that allowed them to construct simplified versions of complex optical objects, including cinematographs and microscopes, which helped to raise their aspirations (see figure 1.17).

Figure 1.17: An example of an early Construments set, marketed as 'Science Made Easy' and something that could make 'Every Boy & Girl a Scientist.'
(Image reproduced from Bill Douglas Cinema Museum, http://www.bdcmuseum.org.uk/explore/item/48011/).

The tagline of Construments ('Science Made Easy') was also similar to Meccano's 'Mechanics Made Easy' branding; the idea of something 'made easy' had also featured in the Hawks' popular science publications and would have told the users of these objects that they provided a means to replicate the complex concepts that they advertised. Similar to the way that Meccano sets carried the tagline 'Engineering for Boys,' Construments was branded as 'Every Boy & Girl a Scientist.' Both brands used these taglines to signify to users that they offered access to real-world science and engineering concepts, education, and skills.[168]

Alongside this, Keene also discusses how the company behind Construments built their marketing for the sets around the fact that they had featured in an article of the *Journal of Scientific Instruments*, where they were described as a 'Protean mechanism.'[169] This was an aspect that Hawks ensured that transferred to Meccano in the 1930s through the development of new specialist scientific sets. These additions to the Meccano brand also continued to raise user aspirations by presenting simplified versions of what scientists and engineers used in these sets. The advertisement of these new specialist scientific sets (Elektron and Kemex) in the *Meccano Magazine* from 1931, reflected the increasing prevalence of the 'eminent engineer' and changing nature of Meccano (see figures 1.18a and 1.18b).

[168] Ibid., p. 268.
[169] Ibid., p. 274.

Figure 1.18a: Adverts for Elektron sets began to dramatically increase towards the end of the 1920s and into the 1930s. The image is of a set advertised from 1933-1940.
(Images reproduced with permission of R. Marriott, Meccano (Shire Publications, 2016)).

Figure 1.18b: Adverts for Kemex sets began to dramatically increase towards the end of the 1920s and into the 1930s. The image is of a set advertised from 1933-1940.
(Images reproduced with permission of R. Marriott, Meccano (Shire Publications, 2016)).

These sets were similar to Construments as they told users that they provided an opportunity to access materials and concepts that were used by experts in a specific scientific field (in this case, electronics and chemistry).

However, unlike with Construments sets, the *Meccano Magazine* also provided Hawks with the means to create content that could help members aspire to be scientists and engineers on a monthly basis. This was evident in the more aspirational tone of the *Meccano Magazine*, evident on the January 1932 front cover, which featured an image of an 'eminent engineer' using a micrometer to measure part of a real-world machine in situ (see figure 1.19).

Figure 1.19: The front cover of a January 1932 issue of the *Meccano Magazine*. (Image reproduced from http://meccano.magazines.free.fr/index.htm).

The magazine also featured a four-page article, 'The Micrometer And Its Story' that gave a detailed history of the micrometer and its use in a real-world context. However, in a development from Hawks' earlier aspiration-raising issues of the *Meccano Magazine*, these newer issues also gave the reader the ability to buy their own micrometer. Through this redesign, the magazine utilised the process of 'Meccano-fication' to simplify concepts and raise the aspirations of readers by telling them that 'the micrometer is in effect as simple as telling the time from one's own watch,' and that owning one them to 'be like' the engineer on display .[170]

Hawks' later attempts to raise the aspirations of users also led to an increase in the number of real-world Meccano models and machines that featured in the magazine. Another example of this Alexandre Rahm's Meccano astronomical clock, which featured in the March 1933 issue of the magazine, titled 'The World's Greatest Meccano Model' (see figure 1.20).


170 THE MECCANO MAGAZINE

The World's Greatest Meccano Model

French Expert's Astronomical Clock

The wonderful Meccano Astronomical Clock with its builder, M. Rahm.

THE MECCANO MAGAZINE 171

View of a section of the interior of the clock, giving some idea of the extraordinary complexity of the mechanism, and of the manner in which every inch of available space is utilised. On the left will be noticed a wheel marked with a cross. This wheel makes a complete turn once in 2,500 years!

Figure 1.20: Alexandre Rahm's Astronomical Clock made from Meccano, featured in the March 1933 issue of the *Meccano Magazine*. (Images reproduced from *Meccano Magazine*, Vol. XVIII, No. 3, (March, 1933)).

The article began by describing Rahm as a 'French Expert,' before detailing how Meccano '[had] been employed with outstanding success by scientists, inventors, and engineers in the

[170] W. F. Harrison, 'Measuring to 1/10,000 of an Inch: The Micrometer and Its Story,' *Meccano Magazine*, Vol. XVII, No. 1, (January, 1932), pp. 2-4: 23.

construction of complicated and delicate apparatus and mechanisms of all kinds.'[171] This told the reader that with his set of Meccano, he too could also create this clock and become an expert like Rahm, raising their aspirations. However, as with the micrometer, the reality of Rahm's clock was not as simple as it was presented. It would have been almost impossible for the readers to build the 9-foot tall astronomical clock from Meccano, due to the high cost of the pieces required and the fact that the clock (as with many of the real-world 'Meccano' models it presented) contained specialist non-Meccano pieces that the magazine did not divulge. In both of these examples, the process of 'Meccano-fication' as a means to simplify concepts and models is evident. It was within this context that Hartree and Porter used Meccano to build their differential analyser in 1934 (see figure 1.21). The impact of 'Meccano-fication' on their object (leading to it being titled as a 'Mechanical Marvel') are discussed further in the following chapter.

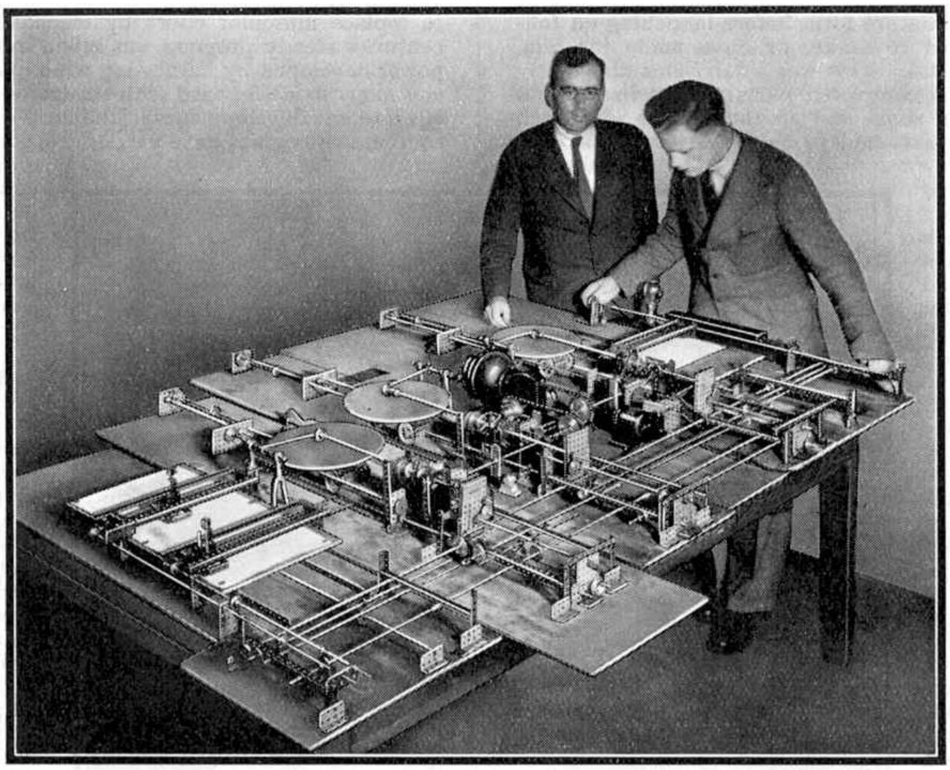

Figure 1.21: The Meccano 'Mechanical Marvel' built by Douglas Hartree and Arthur Porter, as it appeared in the *Meccano Magazine*. (Image reproduced from *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934)).

[171] E. Hawks, 'The World's Greatest Meccano Model: French Expert's Astronomical Clock,' *Meccano Magazine*, Vol. XVIII, No. 3, (March, 1933), pp. 170-171.

Hawks resigned from the *Meccano Magazine* in 1935 and was replaced by McCormick in the final years before the Second World War.[172] During McCormick's tenure, the number of UK-themed covers rose to 71% (from below 40% during Hawks' tenure), while international adventure(r)s and themes were replaced with British engineering machines, which featured on 90% of front covers from 1935 to 1939. Alongside these changes, the 'eminent engineer' character that Meccano boys could aspire to was also replaced with figures using in increasingly patriotic and militaristic ways. This data demonstrates how McCormick used the *Meccano Magazine* to change Meccano into a nationalistic representation of British engineering and replace the 'eminent engineer' character. These changes are evident in a series of front covers from during his tenure, in particular, the March 1939 issue of the magazine 'On Aircraft Work,' which featured an 'eminent engineer' using a machine to build an aircraft for the RAF (see figure 1.22).

[172] R. Marriott, *Meccano* (Shire Publications, 2016), p. 32.

Figure 1.22: The three images from 1938-1939 demonstrate the increasing wartime focus of the *Meccano Magazine*, and the shifting role of the men who featured on the front covers, from using engineering models, to using them for wartime applications. (Images reproduced from http://meccano.magazines.free.fr/index.htm).

This shift in images and language of the *Meccano Magazine* highlight that Meccano was no longer a toy, a training tool for would-be engineers, or an aspirational emblem of fan-participation in international science and engineering. Instead, it was used to signify wartime engineering projects and British values, culminating in the January 1940 image of a roaring lion that was accompanied by the word ‘Challenge!’ (see figure 1.23). Returning to Barthes’ Paris Match image and its ‘fragments of ideology,’ those on this final cover – Meccano, the [British] Lion, and ‘Challenge!’ – would have signified to readers that Meccano represented both British values and engineering.[173] This analysis of Meccano and the magazine suggests that it was McCormick’s version – from the final years before the Second World War, when Meccano was used to signify British engineering, patriotic images, and British values – that the conventional public histories of Meccano, written by Bowler and Wainman, have been based.

Figure 1.23: The January 1940 ‘Challenge’ *Meccano Magazine* cover featuring the ‘British’ Lion. (Image reproduced from http://meccano.magazines.free.fr/index.htm).

[173] R. Barthes, *The Elements of Semiology* (London, 1967), pp. 91-92.

7. Conclusion

This chapter has provided a challenge to Kroto's synchronic history of Meccano as a synecdoche for British engineering, demonstrating that this perspective, along with previous historical analyses of Meccano and the *Meccano Magazine*, have been built on what Anderson calls a 'particular solidarity.' This 'particular solidarity' is a belief that because Meccano did not change physically before the Second World War, it represented a static set of virtues and attributes that were used by a homogenous set of would-be engineers, or an 'imagined community.'[174] However, through analysing the different themes and signifiers used in Meccano sets, marketing materials, and the *Meccano Magazine*, this chapter has demonstrated that different versions of Meccano were developed and communicated to users before the Second World War. The development of these themes alongside the user's responses in the magazine, provide a contrast to the conventional public history of Meccano as a synchronic toy that was a synecdoche for British engineering, instead demonstrating that the users of Meccano were a non-homogenous group who engaged with Meccano in myriad ways.

The next chapter builds on this understanding of Meccano by explaining the 'nuts and bolts' of the original differential analyser, including detailed descriptions of how it worked and functioned mathematically. The second part of the chapter analyses how the processes of 'Meccano-fication' changed the original differential analyser from Hartree and Porter's 'demonstration model' into the 'Mechanical Marvel' in the *Meccano Magazine*.

[174] B. Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism* (Verso, 1983), p. 133.

Chapter Two – Meccano, Mathematics, and Accuracy before the Second World War: The ‘Nuts and Bolts’ realities of the Differential Analyser

1. Introduction

Hartree and Porter used Meccano to build the first UK differential analyser at the University of Manchester in 1934 (see figure 2.1). They used their machine to mechanically integrate differential equations and calculate the rate(s) of change of different input variables. Previously, the solutions to these equations had been calculated using the hand-computed method, which had resulted in a high number of often undetectable errors.[175] Instead, their analyser used the process of mechanical integration, which involved converting the input variables of an equation into continuously-changing physical quantities. These equation variables were translated into the rectilinear displacement and rotation speed of the glass integrating disc on the analyser, which produced an output that was then drawn graphically on an output table. This new mechanical method of calculating equations made Hartree and Porter’s Meccano differential analyser one of the earliest mechanical analogue computers.

Hartree and Porter used ‘The Construction and Operation of a Model Differential Analyser’ (1934) to explain how their machine was a response to the historical accuracy challenges that the hand-computed method had caused for mathematicians over the previous centuries. They then introduced and explained how their Meccano analyser worked as a ‘demonstration model,’ breaking it down into individual units, telling the reader that ‘...it worked much better than was expected, and appeared to be capable of quantitative

[175] The desk calculating machines from this time could only complete the main four arithmetic functions: addition, subtraction, multiplication, and division, and so were not useful for the processes related to calculus.

work…with a 98% accuracy rate.' They finished their article by explaining that the unexpected success of their 'demonstration model' highlighted that 'the development of a mechanical method, accurate and wide in scope, is an advance of considerable importance, with a very wide range of possible applications.'[176]

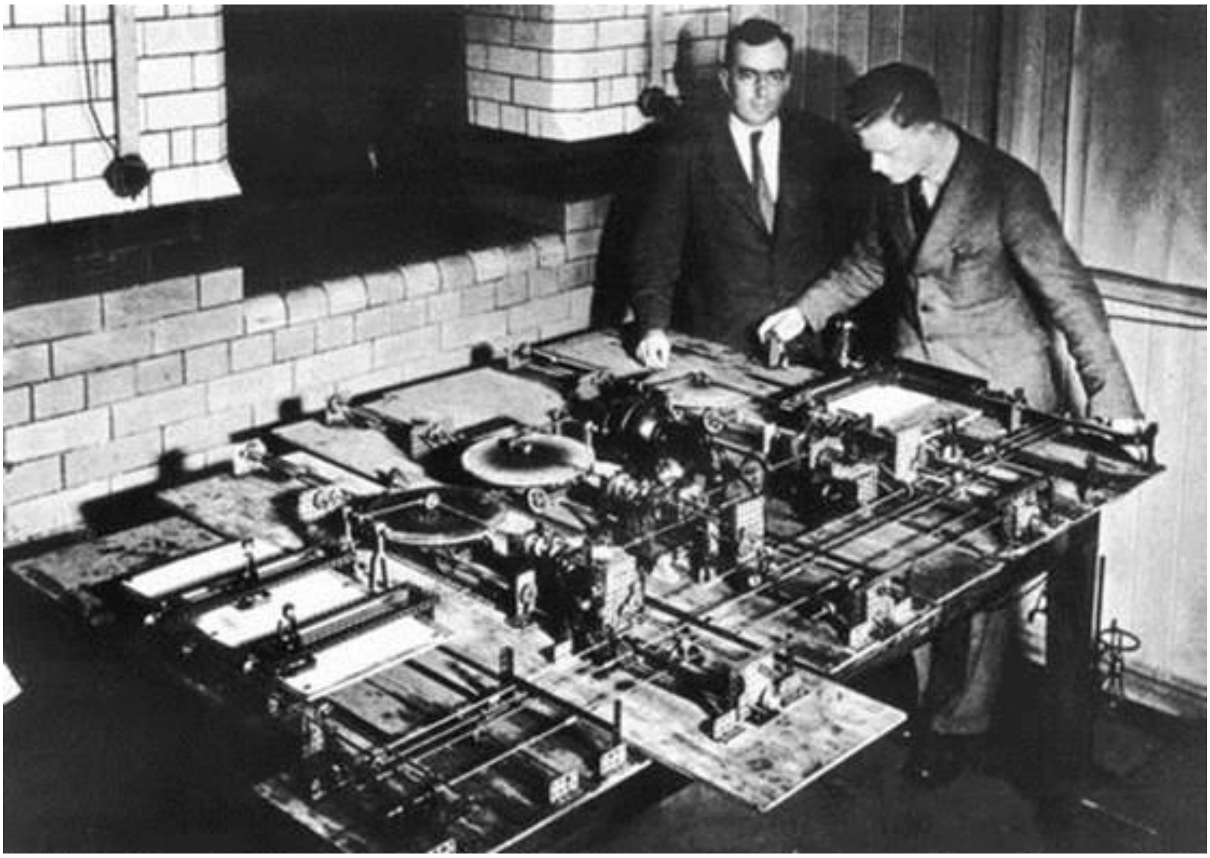

Figure 2.1: An image of the original Meccano differential analyser built by Douglas Hartree (L) and Arthur Porter (R) in 1934. (© Science and Industry Museum Informal Collection).

Hartree and Porter used their Meccano analyser to resolve the atomic wave functions for potassium, caesium, nitrogen, and sodium, which were published in a series of papers in 1934 and 1935.[177] The success of their Meccano analyser inspired various academics to create their own versions of the differential analyser before and during the Second World War, which are

[176] D. R. Hartree and A. Porter, 'The Construction and Operation of a Model Differential Analyser,' *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, Vol. 79, (1934), pp. 51-52.

[177] D. R. Hartree, 'Results of Calculations of Atomic Wave Functions II – Results for K and Cs,' *Proceedings of the Royal Society,* Vol. 143 (850), (London, 1934), pp. 506-517; D. R. Hartree and W. Hartree, 'Self-Consistent Field, with exchange for Nitrogen and Sodium,' *Proceedings of the Royal Society,* Vol. 193 (1034), (London, 1934), pp. 299-304; and D. R. Hartree, and W. Hartree, 'Results of Calculations of Atomic Wave Functions III – Results for Be, Ca and Hg,' *Proceedings of the Royal Society,* Vol. 149 (867), (London, 1935), pp. 210-231.

explored further in Chapter Three. Instead, this chapter will focus on how the first one in the UK functioned, and contrast the 'nuts and bolts' material realities of the machine with the immaterial realities of how it was written about by Hartree, Porter, and others in academic and popular publications.

The chapter will do three things to understand the material and immaterial realities of the machine better and try to answer this question. The second and third sections will look at the historical context that led to the development of the mechanical integration method, before exploring how the accuracy of the machines and humans became entangled. This will highlight that accuracy is not a concrete concept, and explain how, despite being described as having accuracy rates above 98%, the physical form of the differential analysers meant that they were only 'accurate enough' in some contexts and not others. The fourth and fifth sections will then present Hartree and Porter's Meccano analyser conceptually and physically.

While explaining 'nuts and bolts' of the machine in the middle rather than at beginning may seem unusual, this structure is intentional. The Meccano differential analyser is purposely discussed first in the accuracy section to reflect how these machines tend to feature in previous histories of computing, which presume an existing knowledge of both their structure and function. These sources present these machines as concepts rather than physical models in what appears to be another symptom of the 'analogue gap.' To be clear, any difficulty in initially understanding the machine and how it functions in section four and five is intentional. The subsequent 'nuts and bolts' section approaches the analyser from a physical, 'nuts and bolts' perspective to better explain the realities of Hartree and Porter's machine functioned. It will explain what each unit was made from, how each unit worked and how the design of the original differential analyser differs from the reproduced Kent machine. It will also use a real-world example to demonstrate how an equation is translated into the mechanical method of the machine and back out again as an output curve. It presents the machine in a way that assumes no knowledge on the part of the reader. Through adopting this 'nuts and bolts' approach to the machine, these contrasting sections highlight the realities and challenges of its design and application, demonstrating that the 98% accuracy rate of the Meccano analyser was an arbitrary figure, which resulted in it being presented with an inflated usefulness.

The sixth section will then contrast the immaterial concepts and material 'nuts and bolts' of the differential analyser established in previous sections with the various public presentations of the original differential analyser as the 'Mechanical Marvel' and 'Meccano Mechanism' in the June 1934 issue of the *Meccano Magazine*. This will demonstrate that the 'nuts and bolts' realities of the Meccano analyser did not feature in these representations before the war, due to the phenomenon of 'Meccano-fication,' which was an extension of the aspirational emblem version of Meccano described in Chapter One. The conclusion will then demonstrate how the differential analysers began to be 'accurate enough' again after the onset of the Second World War, further highlighting the importance of context to the concept of accuracy and application of these types of analogue computing machines.

2. Context

For a circle to be 'perfect,' all parts of the circumference must be equidistant from its central point, which is calculated using pi (3.1415…). The challenge of creating a 'perfect circle' is that despite humans now knowing trillions of digits of pi, the most accurate human-made circular shape that exists today remains a few millionths of a centimetre from perfection.[178] The 'perfect circle' is impossible outside of pure mathematics because pi is an infinite and irrational number. Therefore, all circular-shaped objects – whether naturally occurring (the Sun, the Moon, the Earth) or human-made (the wheel, the Vitruvian Man, and the modern gyroscope) – are only categorised as circles/spheres because as a society we agree that they are 'circular enough.'[179] The circle as a socially constructed concept is a useful analogy when trying to understand the 'nuts and bolts' instrumentality of Hartree and Porter's 1934 Meccano differential analyser. The analogy is also useful as circles feature prominently in the history of the mechanical method and differential analysers, including in William Shanks' hand-computing woes (explained further below), the design of the wheel-and-disc integrating unit on the differential analyser, and the 'circle test' equation that Hartree and Porter used to measure the accuracy rate of their new calculating machine.[180]

Before the development of the modern digital supercomputer that can calculate and check the digits of pi to 22 trillion places in little more than three months, mathematicians worked their entire careers to hand-compute just a few hundred.[181] William Shanks –

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[178] Anon., A Description of the Most 'Perfect Circle' Constructed by Humans: The NASA Gyroscope, http://einstein.stanford.edu/TECH/technology1.html [accessed 1 July 2018].

[179] For the purpose of this chapter, the discussion of the 'perfect circle' also incorporates the shape of a sphere.

[180] The circle also features in Charles Babbage's — and later Lord Kelvin's — attempts to build their own mechanical calculating machines. They were forerunners of those created in the 1930s, in response to the challenges of the hand-computed method that are exemplified by William Shanks' hand-computed work to increase the number of known digits after the decimal point of π in 1873 (to create a more 'perfect circle').

[181] T. Revell, 'Celebrate Pi Day with 9 Trillion more digits than ever before,'

considered 'one of the finest computers of the Victorian era' – began calculating digits of pi after the decimal point in 1850 and finished in 1873, publishing pi up to 707 decimal places. He beat the previous record-holder, William Rutherford, who had calculated pi to 440 decimal places in 1853.[182] Shanks' approximation of the digits of pi was not surpassed until 1944 when David Ferguson achieved 620 correct places (this was extended to 1,120 in 1949).[183] It was in the course of Ferguson's work that an error in the 528th place of Shanks' work was highlighted, 70 years after it had first been made. The reason Shanks' error had taken so long to find was that because it was not related to the computation of the arctangent formulas that he used to calculate the digits of pi. Forensic mathematician, Erwin Engert, later concluded that a simple transcription error had caused Shanks' mistake. He believed that it most likely occurred when Shanks (or an assistant) had copied 210 digits of a repeating decimal, in order to extend the digits of pi from the 528th to the 609th place.[184] Therefore, despite decades of diligent hand-computing, Shanks' work was undone by something as simple as forgetting to write the zero in the sequence of numbers below.

Correct Arctan Sum Number – 7444668008<u>0</u>48389738430583501

Shanks' Arctan Sum Number – 7444668008483897384305835010

Shanks' example characterises the fraught and inaccurate nature of the hand-computing method that was employed to calculate equations throughout the nineteenth and early twentieth centuries. This was a type of unknowable human-error that undermined

https://www.newscientist.com/article/2124418-celebrate-pi-day-with-9-trillion-more-digits-than-ever-before/ [accessed 15 October 2018].

[182] D. H. Bailey, J. M. Borwein, P. B. Borwein and S. Plouffe, 'The Quest for Pi' *Mathematical Intelligencer*, Vol. 19 (1), (1997), p. 54.

[183] Ibid., p. 55.

[184] B. Hayes, 'Pencil, Paper, and Pi,' https://www.americanscientist.org/article/pencil-paper-and-pi [accessed 1 September 2018].

mathematics in this period, which primarily caused problems in the calculation and tabulation of logarithmic tables. These were used – among other things – to create artillery firing tables. Similar to Shanks' work on pi, a single error in these tables would be compounded in subsequent equations and places in the table, leading shots to be fired that had reduced accuracy.[185] As ballistics technology improved and the distances that artillery could be fired increased, the errors in the hand-computed tables began to have a more pronounced effect, leading many to look for new methods to calculate equations. The accuracy challenge of these hand-computed tables became so problematic that John Herschel wrote to the Chancellor of the Exchequer Henry Gouldburn in 1842, explaining that 'An undetected error in a logarithmic table is like a sunken rock at sea yet undiscovered, upon which it is impossible to say what wrecks may have taken place.'[186]

Despite the widespread knowledge that the hand-computed method was flawed, these firing tables were still used because they avoided the higher error rates that occurred when the same calculations were hand-computed while under pressure in battle.[187] The value of these pre-computed firing tables was that they provided a base-accuracy guideline for gunners, who could correct for any probable error by employing the 'should hit–did hit' method of fire.[188] In other words, they were 'accurate enough.' This example demonstrates that accuracy is not an absolute concept, but is relative to the context in which it was required, deployed, and used. This idea is explored further – in relation to the mechanical method of Hartree and Porter's differential analyser – in the following section.

[185] D. H. Bailey, J. M. Borwein, P. B. Borwein and S. Plouffe, 'The Quest for Pi' *Mathematical Intelligencer*, Vol. 19 (1), (1997), p. 52.
[186] M. Campbell-Kelly, W. Aspray, N. Ensmenger, and J. R. Yost, *Computer: A History of the Information Machine* (Westview Press, 2014), p. 24.
[187] M. Campbell-Kelly, and W. Aspray, *Computer: A History of the Information Machine*, (Perseus Books, 2004), p. 72.
[188] C. H. Lebegern, Jr, 'On the Misuse of Field Artillery Firing Tables,' *Ballistics Research Laboratories Memorandum Report*, No. 2281, (March, 1973), p. 7.

Herschel also had conversations about the inaccuracy of the hand-computed method with Charles Babbage, whose solution in reply was 'I wish to God these calculations had been executed by steam.'[189] Babbage's belief that steam was consistent and did not discriminate translated to the design of his mechanical Difference Engine in 1822 and Analytical Engine (Difference Engine No. 2) in 1837. He designed these machines to turn mathematical equations into a series of mechanical processes, which would remove the possibility of human error. While Babbage's work serves as one of the foundations of modern-computing technology from a theoretical perspective, his attempts to make these mechanical calculating machines were unsuccessful.[190] One of the primary reasons for this failure was due to a lack of torque, which meant the variables of the equation could not be driven through to the output elements of his machines after they had been calculated. Torque is the measurement of the force that is used to rotate an object about an axis; in mechanical-calculating machines, torque relates to the rotation of threaded screws between different units. The issue of low torque also hampered the work of Lord Kelvin and James Thomson, who tried to build a similar mechanical calculating machine to Babbage in the 1870s. It would not be until after the creation of a torque amplifier by Henry Nieman in 1925 that this challenge of low torque in mechanical machines was resolved.[191]

Vannevar Bush and his colleague Harold-Locke Hazen used this new device to successfully build a series of increasingly complex mechanical desk calculators in the 1920s and 1930s. These included the Network Analyser, the Product Intergraph, and the first

[189] Babbage recalling his conversation with John Herschel from 1821, quoted in W. B. Harry and A. Hyman, *Memoir of the Life and Labours of the Late Charles Babbage*, (MIT Press, 1988).
[190] Babbage's attempts and failure to build these machines are discussed further in D. Swade, *The Difference Engine: Charles Babbage and the Quest to Build the First Computer*, (Viking, 2000); D. Swade, *The Cogwheel Brain* (Abacus, 2001); D. Swade, 'The Calculation and Tabulation in the Nineteenth Century: Airy versus Babbage,' (Ph.D. Thesis, 2003); and W. Isaacson, *The Innovators*, (Simon and Schuster, 2014), p. 37.
[191] US Patent No. 1,751,645, H. W. Nieman, 'Servomechanism,' (25 March 1930).

differential analyser, the MIT differential analyser in 1931.[192] Bush wrote that 'the MIT machine incorporates the same basic idea of interconnection of integrating units as did [Lord Kelvin's]. In detail, however, there is little resemblance to the earlier model.'[193] Bush's use of the torque amplifier increased the output torque of his machine, which meant that the rotations of the wheel-and-disc integrator (the output integral) could drive the output components of the machine.[194] The successful construction of the MIT differential analyser allowed Bush to realise Babbage's vision and mechanise the arithmetical processes of addition, subtraction, multiplication, division, and crucially calculus.[195] While mechanising these processes increased the speed of calculation, and the level of accuracy of the output, the mechanical method of the machine created a new set of challenges that will be analysed further below. However, for the period after Bush had successfully constructed it, the mechanical machine was 'accurate enough' to become the primary method of calculating differential equations.

The success of Bush's machine in mechanising integration prompted Hartree to visit MIT and see Bush's machine, commenting that 'it looked as if someone had been enjoying himself with an extra-large Meccano set.'[196] On his return to the United Kingdom, Hartree immediately set about working with his research student, Arthur Porter, to develop their own version of the differential analyser. They decided to use the children's construction toy, Meccano, with Porter initially constructing a single-integrator 'proof-of-concept' model,

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[192] For more on this, refer to: D. Mindell, *Between Human and the Machine: Feedback, Control, and Computing before Cybernetics* (Johns Hopkins University Press, 2002), p. 153; and S. Bennett, *A History of Control Engineering, 1930-1955* (London, 1993), p. 103.
[193] V. Bush, 'The Differential Analyser. A New Machine for Solving Differential Equations,' *Journal of the Franklin Institute*, Vol. 212, (1931), p. 448.
[194] D. R. Hartree, 'The Bush Differential Analyser and its Applications,' *Nature*, Vol. 146, (3697), (1940), p. 319.
[195] J. Crank, *Differential Analysers*, (Longmans, 1947), p. 2.
[196] C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing*, (World Scientific Publishing, 2003), p. 71.

which he used to calculate the first-order differential equation for the atomic wave functions of hydrogen.[197] The success of this model led Hartree to work with Porter to develop the single-integrator Meccano object into a three-integrator Meccano analyser in 1934. Porter was the first to test the analyser as part of his MSc thesis, using it to resolve equations related to the atomic wave functions of Chromium atoms.[198] The Meccano analyser was subsequently presented in articles and journals as a 'demonstration model' that possessed a 98% accuracy rate and could solve previously 'unsolvable equations.'[199] While neither of these statements was untrue, the mechanical method of the analyser is slightly more complicated than they suggest. However, before looking at the mechanical method of the machine in more detail, the next section looks at the concept of accuracy, highlighting that while the machine resolved many of the challenges Shanks and others had faced, it introduced new problems of its own.

[197] Porter used the already known solutions of the self-consistent field equations for atoms of hydrogen to calibrate the object when it had been completed. This work was included as part of his MSc. Thesis.
[198] Science and Industry Museum Archives, SIM 510.8, A. Porter, 'The Construction of a Model Mechanical Device for the Solution of Differential Equations, with Applications to the Determination of Atomic Wave Functions,' (MSc. Thesis, University of Manchester, 1934).
[199] Science Museum Archives, Sc. M. 1949-134/3.Anon., 'Most Wonderful Machine In Europe Made From Toy,' *News Chronicle*, (8 February 1935).

3. Accuracy

Despite their 'imperfect nature,' circles are used to measure accuracy in both mathematical and non-mathematical contexts. Dartboards and archery targets are two examples of this, though they do so in different ways. The highest level of accuracy achievable with an archery target is in the centre of the circular target, while on a dartboard it is in the 'treble 20' part of the ring that sits roughly halfway between the centre and edge of the board. The difference between what is 'accurate enough' in these examples demonstrates that accuracy is a context-specific concept.

Donald MacKenzie's *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (1990) includes a case study about the testing of nuclear warheads as an example of the context-specific nature of accuracy in mathematics. His work explores the missile accuracy of the US nuclear arsenal, discussing how the results from a live testing range were extrapolated to represent the accuracy of the missiles. He explains that the difference between the intended target and actual impact points of missiles in testing were used to create a circular error probable (CEP). The radius of this circle centred on a mean point, within which it was expected that 50% of the fired warheads would fall, with the rest following a normal distribution pattern.[200] Figure 2.2 is an example of the CEP concept, with the image on the left representing the distribution of 20 missiles. The CEP on the right is a version with a 95% confidence interval; that is when a certain number of missiles are launched – in this example 20 – 50% are expected to land within the first circle around the mean, 40% in the

[200] D. MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (The MIT Press, 1990), p. 346.

second circle, 5% in the third, and 5% outside of the circles. MacKenzie explains that the percentages of each CEP confidence interval are created using the 'test data' in the left image.

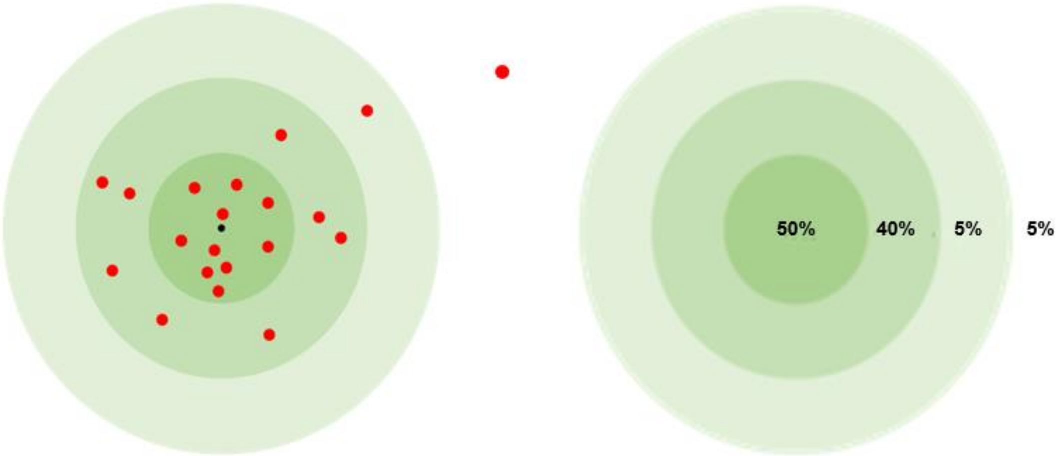

Figure 2.2: The image on the left represents a 20-missile distribution example sample, while the image on the right represents the CEP concept, including the different confidence intervals. (© Creative Commons BY-SA, 4.0).

MacKenzie's central criticism of the CEP concept was that the confidence intervals of where the missiles would fall did not correlate to where the missiles actually fell on the Vandenberg-Kwajalein test range. Instead, he asserted that there was a gap between the CEP estimates and the subsequent locations of where the missiles would land; a result of what he called an 'accuracy bias.'[201] He explained that this 'accuracy bias' was the result of the laboratory processes used to measure the missiles' landing zones on testing ranges, which was then used to formulate the CEP and confidence intervals. He asserted that the operators who measured where missiles fell became increasingly 'competent' at the processes of testing as successive tests were carried out.[202] He argued that this increased competence led to a reduction in the human testing and measurement errors (but only in laboratory testing conditions), which fostered a belief that the missiles would hit with a higher level of accuracy and precision than if they were fired in real-world conditions (where it was much more difficult to account for, and resolve, the testing and measurement errors).

[201] Ibid., p. 345.
[202] Ibid., p. 347.

MacKenzie argued that this 'accuracy bias' made it appear as if the accuracy rates of missiles were increasing, when no improvements had been made to the hardware.[203] Tsipis also argued that 'repeated tests over the same range have internalised a very substantial bias which remains unknown' in his article 'Precision and Accuracy' (1981).[204] Echoing Tsipis, a retired American General also wrote about the challenges associated with extrapolating accuracy rates from these types of testing contexts into real-world contexts. He stated that 'about the only thing that's the same [between the tested missile and the Minuteman ICBM in the silo] is the tail number.'[205] Despite these warnings about an 'accuracy bias,' politicians pushed for larger warheads on ICBMs, based on the 'increased accuracy and precision' of tests, which they believed meant that there was a lower risk of hitting an unintended target.[206] This example demonstrates that rather than an absolute concept, whether or not something is 'accurate enough' depends on the context in which accuracy is derived and applied.[207] Put simply, the 98% accuracy rate of Hartree and Porter's machine does not tell the complete story of these machines. Instead, we must look at the 'circle test' for accuracy that they used to get the 98% figure, questioning its 'accuracy bias' and how representative this rate was for other equations.

Hartree and Porter used the 'circle test' for accuracy when measuring the calibration of the different mechanical units of the object (mechanical accuracy). They used an equation that plotted a sine curve against a cosine curve:

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[203] Ibid., p. 347.
[204] K. Tsipis, 'Precision and Accuracy,' *Arms Control Today*, (May, 1981), p. 4.
[205] A. T. Hadley, 'Our Ever-Ready Strategic Forces: Don't Look Closely If You Want To Believe,' *Washington Star*, (1 July 1979).
[206] R. T. Marsh, USAF, 'Strategic Missiles Debated: Missile Accuracy-We Do Know,' *Strategic Review*, Vol. 10, (Spring 1982), p. 37.
[207] A. T. Hadley, 'Our Ever-Ready Strategic Forces: Don't Look Closely If You Want To Believe,' *Washington Star*, (1 July 1979).

$$\frac{d^2y}{dx^2} = -y$$

As the equation has constant coefficients, there was no need for a human operator to follow an input line, as with other equations programmed into the differential analyser. Instead, configuring the differential analyser for the 'circle test' requires creating a feedback mechanism. To do this, Hartree and Porter would have connected the output of the first integrator to the rectilinear displacement of the second integrator, while also connecting the output of the second integrator to the rectilinear displacement of the first integrator. Then in order to begin the 'circle test,' the steel wheel on the second integrator would be set at the centre of the glass disc (the 'null point'), while the first integrator would be displaced so that the steel wheel was a set distance (y) away from the null point of that glass integrating disc.[208] When turned on, the second integrator would govern the movement of the x-axis of the pen on the output table, while the movement of the first integrator would direct the y-axis. Therefore, despite measuring the accuracy of the differential analyser, the configuration of the circle test means that it cannot measure the effect of the human input required to programme an equation into the input table and calibrate the integrating unit of the differential analyser.

The output curve of the 'circle test' equation ($-y$) represents a circular shape. If the output curve is a 'perfect circle,' the analyser would have a mechanical accuracy rate of 100%. However, the mechanical nature of the machine and the integrating units mean that the integrated sine curve of the 'circle test' will always deviate from the true sine curve, which means that these machines can never have an accuracy rate of 100%. Instead, the 98%

[208] The 'null point' is at the centre of the glass rotating disc. The steel wheel does not rotate until it moves from the 'null point' as the equation integrates.

accuracy rate of Hartree and Porter's machine means that it would create an output curve for the 'circle test' that was a tight spiral shape, where the two ends of the circle did not meet. This shape was the result of the circle having flattened edges at its four algebraic maxima and minima of $x, -x, y$ and $-y$. These flattened edges were caused by the rectilinear displacement of the steel wheels through the 'null points' of the glass discs on which they sat. When this happened during the 'circle test' equation, the rotation of the steel wheel would pause briefly. As the other steel wheel would be at its furthest from the 'null point' at this point in the equation, the pen on the output table would move in a straight line on the axis that that integrator controlled.

For Hartree and Porter's analyser, the mean variation of these deviations between the average curve and the actual sine curve was (on average) 0.5%. With four peaks of the sine curve in each circle (or cycle of the object), the 0.5% mean-difference between the output line and the true sine curve at each peak of the circle resulted in a 98% accuracy rate per completed run of the 'circle test' equation. However, MacKenzie's criticism of the 'accuracy bias' of CEP missile tests also applies to the 'circle test,' as the accuracy rate that a differential analyser can achieve through this test only reflects the precision of the units of the analyser when they are calibrated for that specific test, and the skill of the operator calibrating them.

In a 2008 interview, Porter explained that the 'circle test' was part of 'routine maintenance; about once every two or three weeks we'd set up the circle test…and how well they [the ends of the output line] join in plotting the circle is effectively how accurately the machine worked.'[209] His explanation demonstrates that the 'circle test' was something that operators of the analyser could become increasingly proficient at setting up. This is because

[209] Arthur Porter, interviewed by Tim Robinson, 8 March 2008, Computer History Museum, X4583.2008.

the calibration of the different units in the machine to integrate and resolve the ‘circle test’ was both relatively simple, and very different from the calibration needed for more complicated differential equations. As a second-order linear differential equation, the ‘circle test’ required two integrators, compared to the four, five, or six, which were necessary for higher-order equations. Therefore, it can be argued that the ‘circle test’ measured the accuracy rate of the operator’s ability to set it up correctly for that specific equation, and not the rate of the machine for other equations.

And yet, even with this relatively simple ‘circle test’ equation, the opportunities for both human and mechanical error are still so high with these machines. An example of this is when we used the Kent machine to resolve the ‘circle test’ on two separate occasions. Despite our best efforts, the machine produced markedly different output curves for the same equation (see figures 2.3a and 2.3b). The top image represents the highest possible accuracy rate that we could achieve with the Kent machine; at 99.3%, the gap between the two ends of the output line is less than the thickness of the pen nib. In contrast, the bottom image was achieved less than an hour after the first, demonstrating the failure of the mechanical parts of the machine. This failure was caused by mechanical slippage that was the result of a lack of friction between the steel wheel and glass disc on the first integrator, which stopped the steel wheel on one of the integrators from spinning consistently.

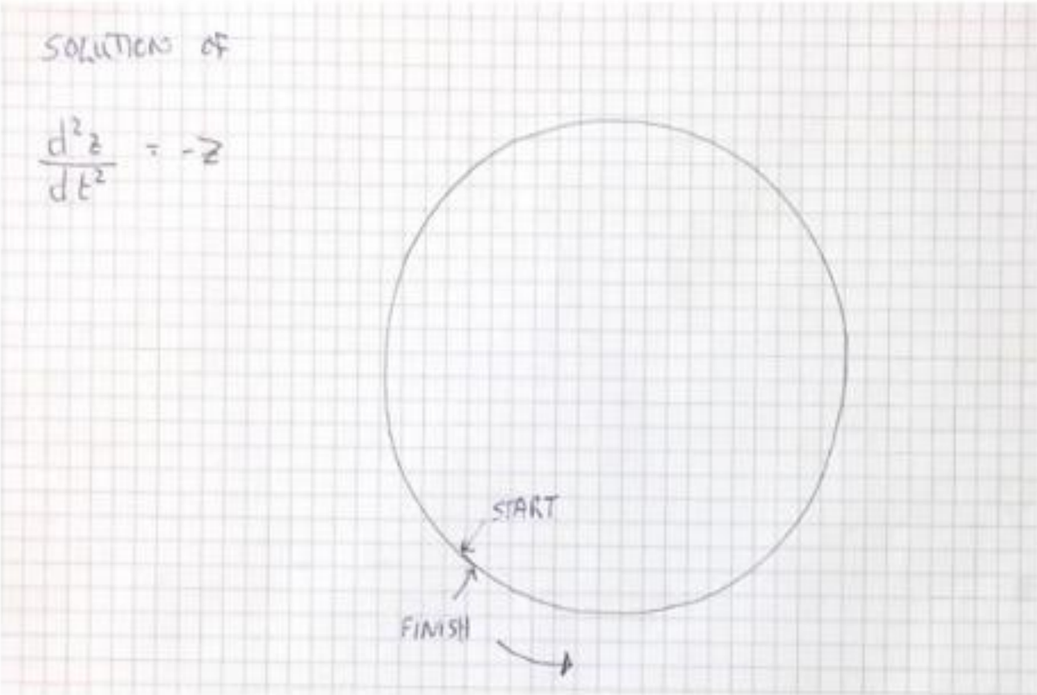

Figure 2.3a: An image of a successful output curve for the ‘circle test’ equation produced by the Kent machine. (Image taken by author).

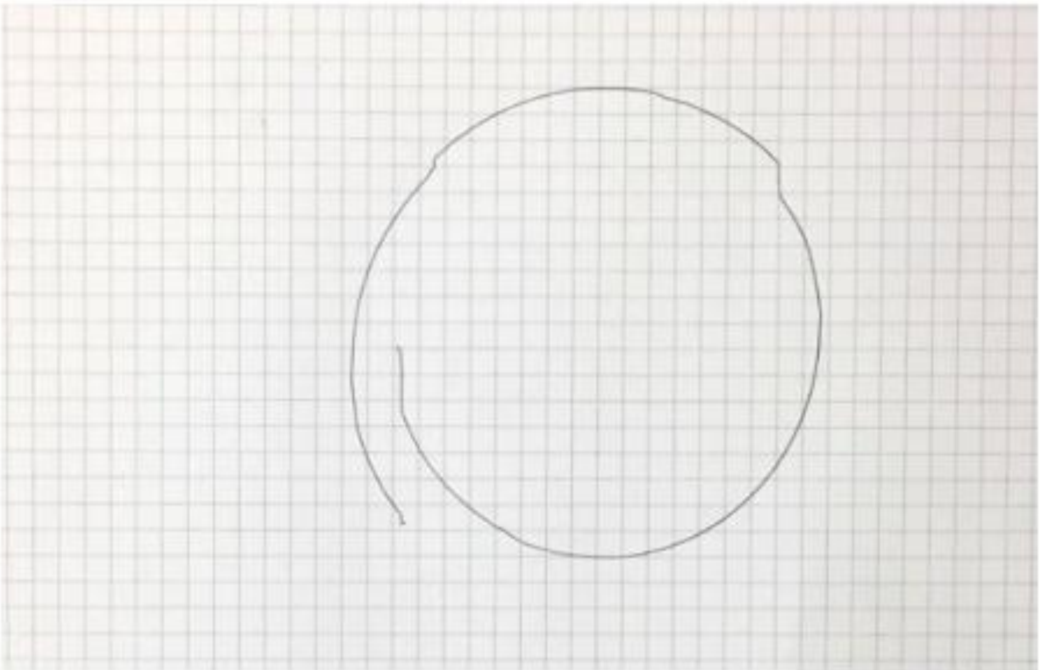

Figure 2.3b: An image of an unsuccessful output curve for the ‘circle test’ equation produced by the Kent machine. The differences between this and the previous image demonstrate the variability of results that differential analysers can produce, highlighting the challenges of the mechanical method and the flawed nature of the ‘circle test’ as a method to measure the overall accuracy of the machine. (Image taken by author).

The examples used in the second half of this section have demonstrated that the accuracy rate derived from ‘circle test’ only measured the accuracy of Meccano pieces and the skill of the operator in calibrating the machine for a specific equation. However, this test did not help to measure the accuracy of the units of the analyser for each equation as it could only measure the accuracy that the most skilled user can achieve when calibrating the machine to calculate the circle test.[210] In this way, the accuracy of the human and machine became entangled and inseparable in the Meccano differential analyser.

To better understand how the units of the machine functioned, the following sections will explore their 'nuts and bolts' realities, demonstrating how different units worked, and the 'workaday problems' of the object.[211] It will establish that while the mechanical method of the differential analyser did increase the speed and accuracy of equations, the 98% accuracy rate did not account for the human arithmetic and transcription errors that were mechanised into the differential analyser, which resulted in a new type of human-induced mechanical error. Exploring and understanding this human-induced mechanical error will help us understand the material and immaterial aspects of the analyser in contrast to how it has been presented in different publications before and after the Second World War. However, before this, the next section introduces the analyser using John Crank's (a former student of Hartree) conceptual presentation from his 1947 publication *Differential Analysers*. The purpose of including his approach is to demonstrate the complex way that these machines have been presented in the history of computing literature, and provide a contrast to the (hopefully) clearer 'nuts and bolts' explanation of the analyser in the subsequent section.

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[210] The accuracy of the output curves of equations physically integrated by the object will always be limited by the inherent inaccuracies of mechanical components. For more information on this, read: Anon., 'Mechanical Accuracy,' https://www.scientificamerican.com/article/mechanical-accuracy/ [accessed 9 July 2018].

[211] A. Warwick, 'The Laboratory of Theory or What's Exact about the Exact Sciences?,' in M. N. Wise (ed.), The Values of Precision (Princeton University Press, 1995), p. 313.

4. The Conceptual Model

In a 2008 interview, Porter described how he and Hartree felt that the model was 'almost miraculous at the time' as it could produce output curves that were the wave functions of different atoms.[212] He explained that this had allowed Hartree and himself to successfully bid for funding for a larger, bespoke version; the Manchester machine, which was delivered by Metropolitan Vickers in 1935.[213] However, in contrast to both Hartree and Porter's claims that the machines were fast, accurate, and 'almost miraculous,' Crank asserted that differential analysers were objects of 'mathematical last resort, for when [the hand-computed approach] fails.'[214] Crank had used differential analysers during the war to assist with his work on numerical ballistics calculations and computational mathematics at the University of Cambridge.[215] His description of the Meccano differential analyser contrasts with how it had been presented before the Second World War by Hartree and Porter, by the press who described it as something that could resolve 'unsolvable equations,' and the *Meccano Magazine* that described it as a 'Mechanical Marvel.'[216] Instead, Crank presented the analyser less as a physical object and more as a conceptual model that was useful only in a narrow context and should only be employed in evaluating numerical solutions of equations that had no formal mathematical solution.[217]

Crank's work has been described as the 'bible for reference purposes' by William Irwin of the Computer Conservation Society, who restored the Cambridge Meccano model

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[212] Arthur Porter, interviewed by Tim Robinson, 8 March 2008, Computer History Museum, X4583.2008.
[213] T. Haigh (eds.), 'Arthur Porter's Autobiography,' *IEEE Annals of the History of Computing*, Vol. 25 (2), (2003), p. 86.
[214] J. Crank, *Differential Analysers* (Longmans, 1947), p. 4.
[215] Professor John Crank obituary, http://www-history.mcs.st-andrews.ac.uk/Obits2/Crank_Telegraph.html [accessed 20 November 2016].
[216] E. Hawks, 'Meccano Aids Scientific Research,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 441.
[217] J. Crank, *Differential Analysers* (Longmans, 1947), pp. 4-6.

differential analyser at the University of Auckland in 2005.[218] It was for this reason that my initial attempts to understand the differential analyser at the beginning of the thesis were made through reading Crank's book (thanks to a Google Scholar search for 'Differential Analysers'). While I was unaware at the time, the series of drawings of different units of the Cambridge Meccano model lacked detail about how these units were connected and functioned. Crank's work is similar to other analogue computing literature, which tend not to explain how differential analysers functioned as working machines, and do not explore the hands-on skills and tacit knowledge required to make a differential analyser work.[219] It is only since going through the processes of reproducing the original differential analyser as the Kent machine that it has become apparent how much knowledge Crank and others assume that the reader already has about the 'nuts and bolts' object when they introduce it

Figure 2.4 is a composite image of the different units of the differential analyser configured for the 'circle test' as they are presented in Crank's book. The left side of the image is of two integrating units, while the right side demonstrates the input and the output table. They are presented in this way in Crank's book with no connections between the input and output tables and the integrating units.

[218] W. Irwin, 'The Cambridge Meccano Differential Analyser No. 2,' *Resurrection: The Bulletin of the Computer Conservation Society*, No. 64, (Winter 2013/2014), http://www.cs.man.ac.uk/CCS/res/res64.htm [accessed 14 January 2017].
[219] J. Crank, *Differential Analysers* (Longmans, 1947), pp. 4-6.

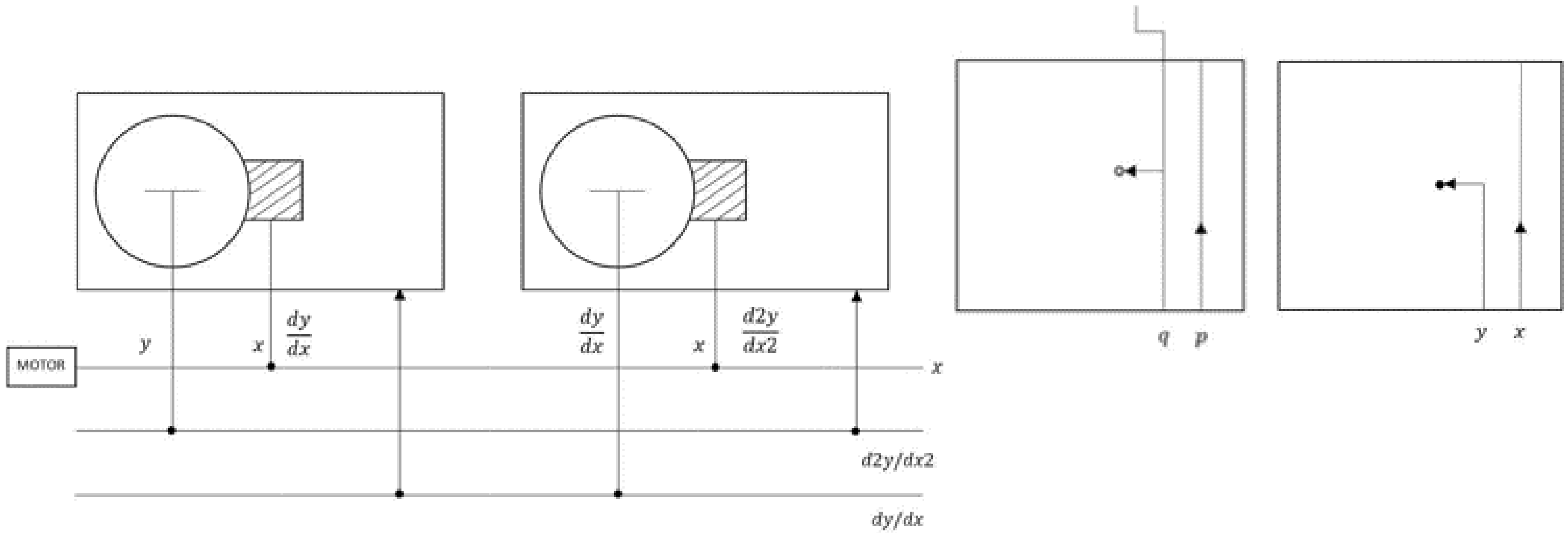


Figure 2.4: A schematic representation of a differential analyser configured to resolve the 'circle test.' This configuration is unique to this equation. (Image drawn by author from images in J. Crank, *Differential Analysers*, (Longmans, 1947)).

Figure 2.5 is the pictographic symbol used to represent the input table of the differential analyser. Crank asserts that the letters 'q' and 'p' relate to the rotations of the lead screws in relation to the input variables of an equation. He explains that when using the input table of the analyser, the input process can be expressed as $q = f(p)$, or q equals the function (f) of p.

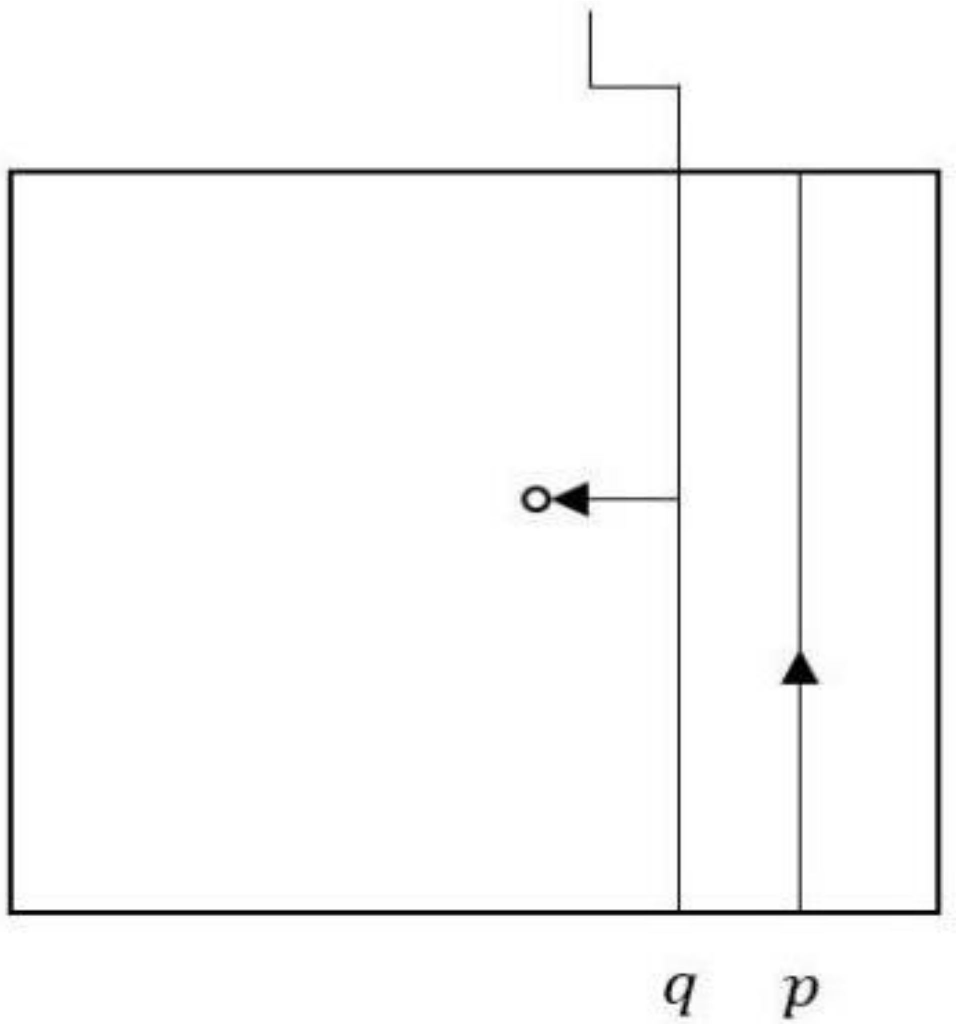


Figure 2.5: A schematic representation of the input table that was used when mathematicians drew the object in different configurations. (Image drawn by author from images in J. Crank, *Differential Analysers*, (Longmans, 1947)).

Figure 2.6 corresponds to the integrating unit of the machine. Crank uses the letters in the image to represent the inputs and outputs of the different shafts of the unit, with the relationship between the rotations of these shafts expressed as $u=\int w\,dv$ when configured for the circle test.

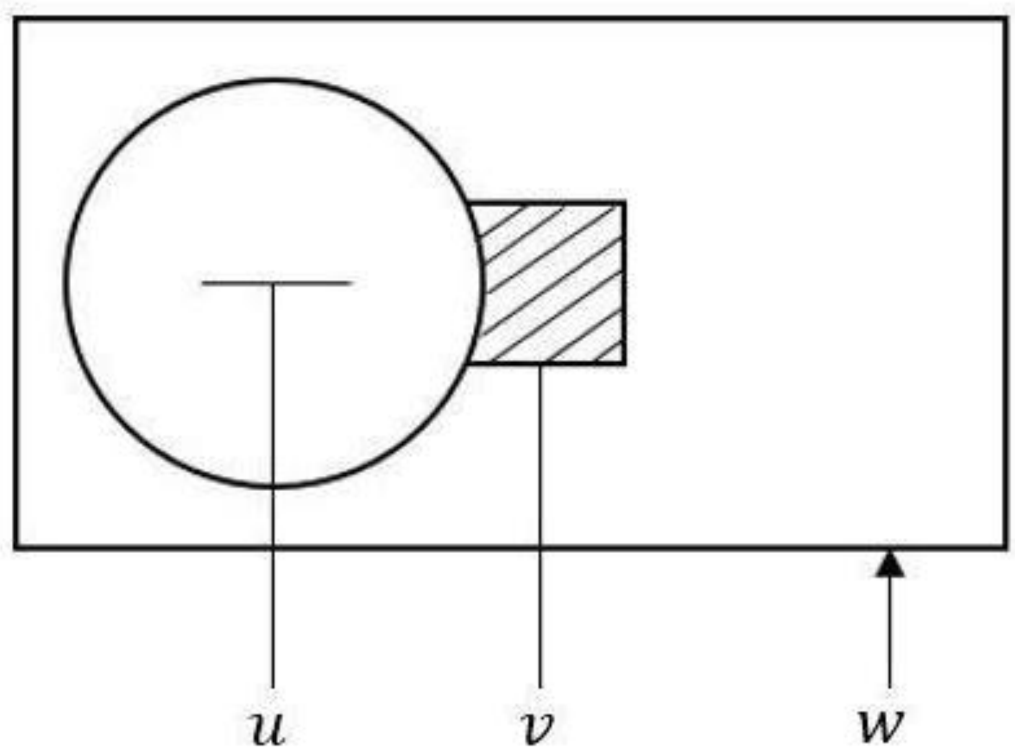


Figure 2.6: A schematic representation of the integrating unit of a differential analyser. (Image drawn by author from images in J. Crank, *Differential Analysers*, (Longmans, 1947)).

Figure 2.7 is a schematic representation of the process of integration that occurs in the integrating unit when the object is configured for the circle test equation. Crank asserts that the value y^1 represents the relative rectilinear position of the glass disc, while x^1 is the rotation speed. He also highlights the rectilinear displacement (y^1) and rotation speed (x^1) of the glass wheel, as well as the point of contact between the glass disc and steel wheel (a), and the output integral arm in the top right corner.

$$\int y^1 dx^1/a$$

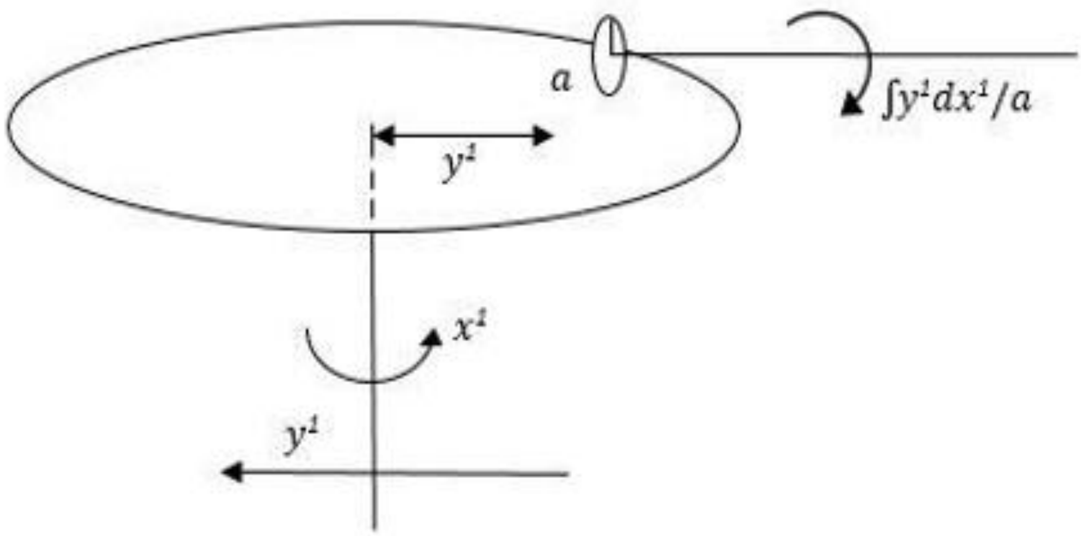


Figure 2.7: A mathematical drawing of the integrating unit configured to resolve the 'circle test.' (Image drawn by author based on those found in J. Crank, *Differential Analysers,* (Longmans, 1947)).

Figure 2.8 is a graphical representation of the output table. Crank tells the reader that the closed circle dot indicates that the table has a stylus, instead of a pointer attached to it like the open circle on the input table. The two letters relate to the output variables of the integrated equation that is expressed as $y = F(x)$. This programmes the curve produced by the output table.

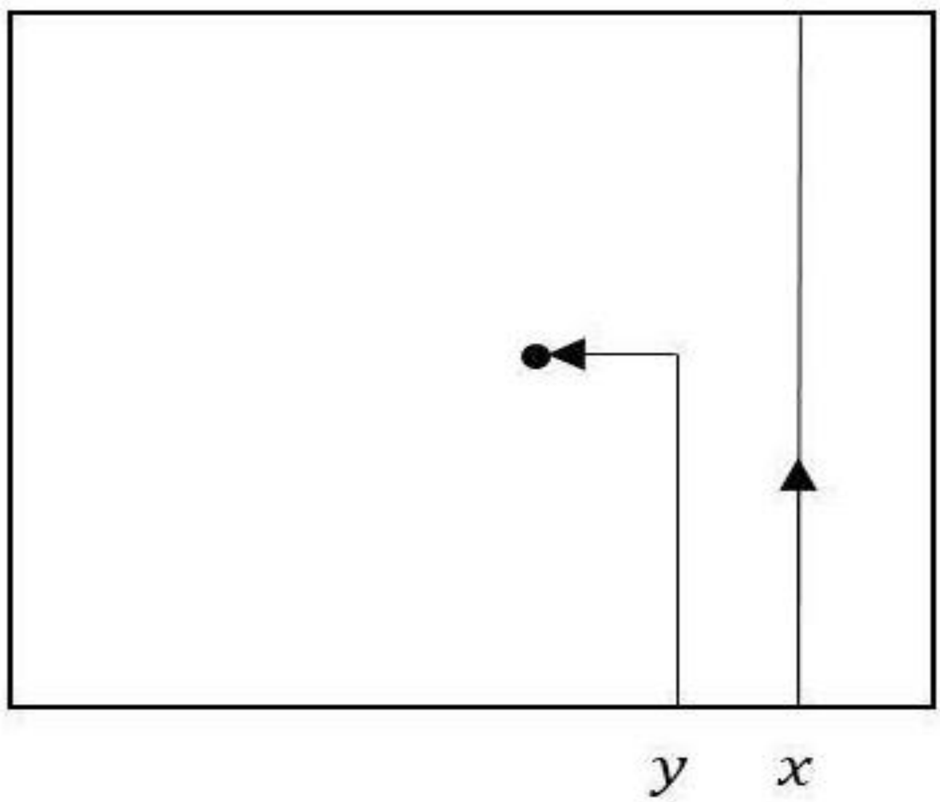


Figure 2.8: A schematic representation of the output table of a differential analyser. (Image drawn by author based on those found in J. Crank, *Differential Analysers*, (Longmans, 1947)).

These schematic images have been included along with the short explanations used to demonstrate how the differential analyser – as it would have been configured for the 'circle test' for accuracy – is presented in Crank's book. While his work explains the object conceptually, it provides few clues about what these machines looked like, or how they actually functioned and resolved equations.

5.1. The Physical Model: The Input Table

The top image in figure 2.9 is the original Meccano differential analyser, while the bottom is an image of the historically reproduced Kent machine. Images of different parts of both of these machines are used throughout this section to help demonstrate how these machines worked, and the connections between each of the different units. The 'nuts and bolts' approach of these subsections should allow a reader to refer back to these images and those in the previous section to both track the movement of the variables of an equation and understand how they are mechanically integrated through the machine.

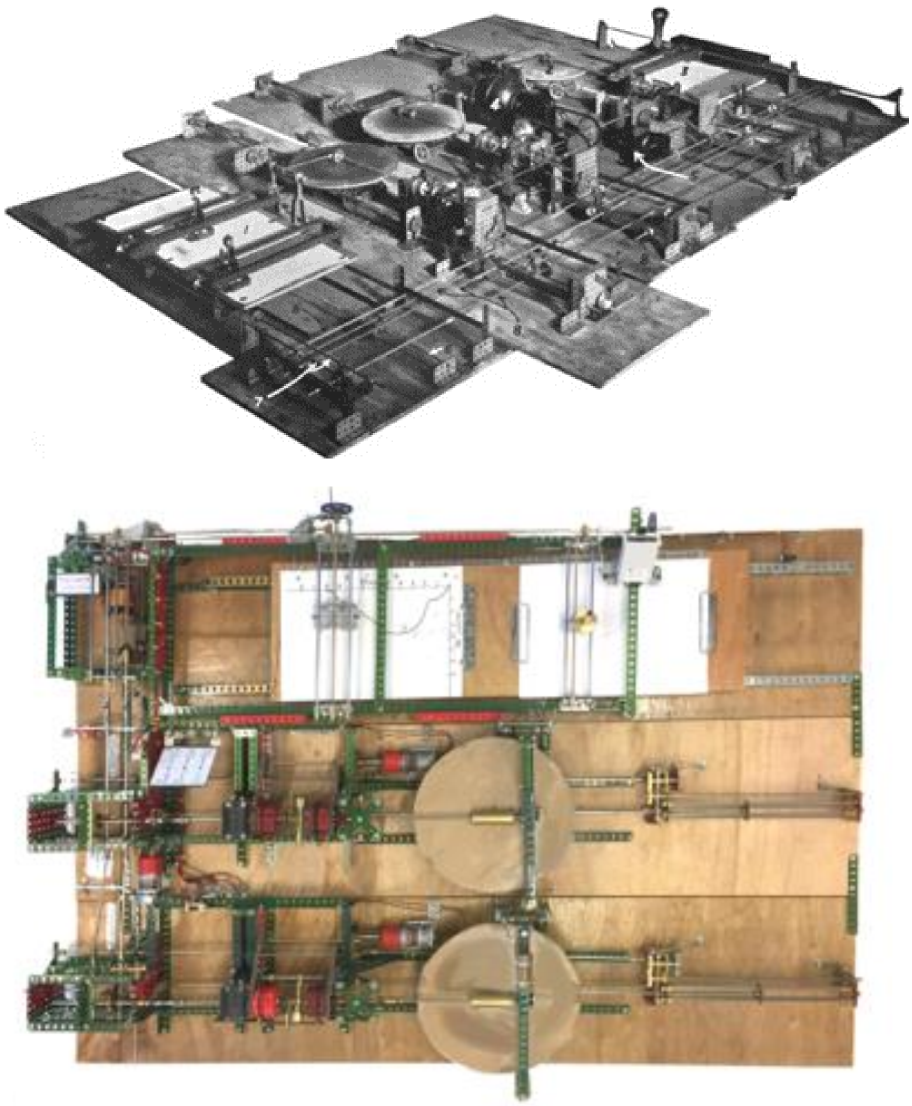
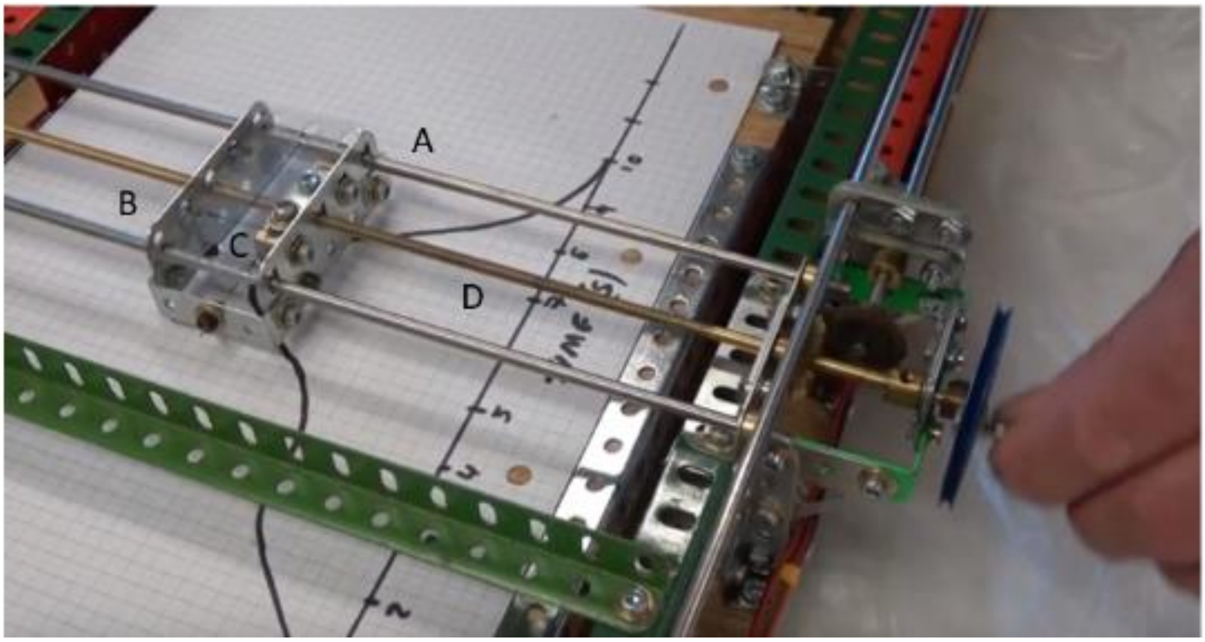


Figure 2.9: The top image is of the original differential analyser. (© Science and Industry Museum Informal Collection). The bottom image is of the Kent machine. (Image taken by author).

The input table was the unit used to programme the variables of the equation into the analyser (as numerical values). Hartree and Porter's input table was constructed from a flat panel of wood on top of which sat a bridge, a carriage, a pointer, and threaded rods that were connected to two lead screws (see figure 2.10).



A: The Bridge   B: The Carriage   C: Pointer/Reticule   D: Threaded Screw

Figure 2.10: An image of the input table of the Kent machine, demonstrating its central components. (Image taken by author).

The numerical values of an equation were calculated and drawn onto a piece of paper as a pre-plotted curve. The shape of the input curve was derived from the known functional relationship between the different variables in the equation. The hand-drawn input curve required precision and took many weeks of preparation, depending on the complexity of the equation. This is the first area where an error could occur in the process of calculating an equation, which would impact the accuracy rate. If this initial curve was even slightly misdrawn, it would have resulted in incorrect equation derivatives being programmed into the input table and machine

The operator would then manually follow the vertical position of the input curve with the pointer, moving it to programme the equation variable on the y-axis. The pointer was made to move by turning a wheel to rotate a threaded screw that sat at a perpendicular angle to the input table. At the same time, the input table automatically moved horizontally. This movement represented the derivative of the equation on the horizontal x-axis, or the 'time drive.' The purpose of the time drive would be to provide a constant derivative rate of change in an equation. Together these two movements of the pointer along the pre-plotted input curve measured the area under the graph, which translated the derivatives of the equation into mechanical components (the lead screws) that programmed the integrating units of the object.

The input table unit of the original differential analyser contained many potential risks of error that would have a dramatic impact on the overall accuracy rate of the object for an equation. There were also certain design choices in the original differential analyser that would have increased the chances that errors could occur. When producing the Kent machine, Ian Henwood and I reduced these risks by designing a different mechanism to track the input curve. Instead of a pointer device (circled in red on the original differential analyser), we included a cross reticule. This made it much easier for us to visually track the vertical position of the line compared to the pointer, which could block the operator's view (see figure 2.11).

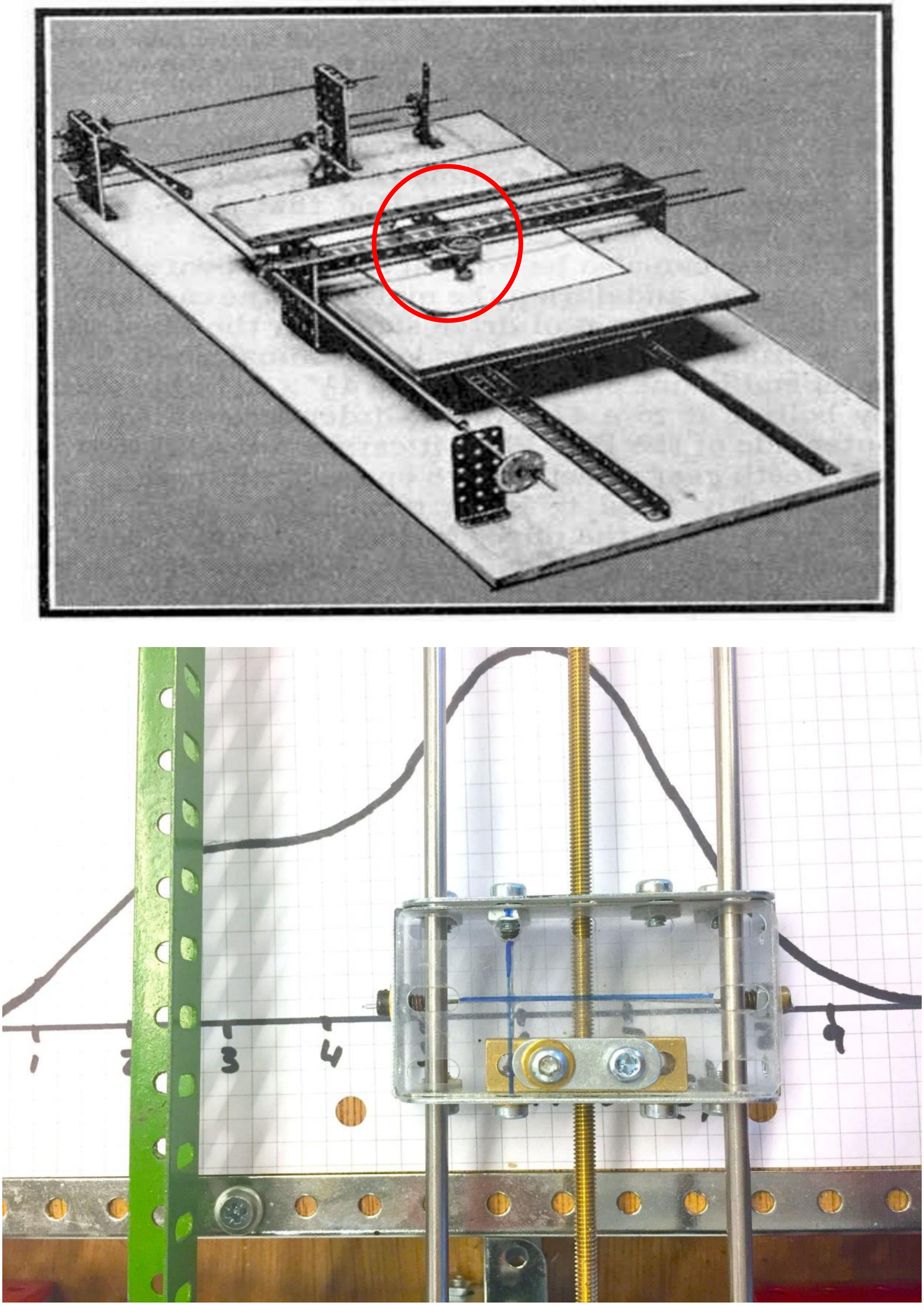


Figure 2.11: The top image is of the pointer device on the input table of the original differential analyser, which featured in the *Meccano Magazine* in 1934. (Image reproduced from *Meccano Magazine*, Vol XIX, No. 6, (1934). The bottom image is of the reticule used to follow the line on the input table of the Kent machine. (Image taken by author).

We also changed the turning wheel on the Kent machine, compared to the original. The turning wheel is the device used to change the vertical position of the object used to track the input curve. On the original differential analyser, this device sat at a perpendicular right angle to the input table (circled in red in figure 2.12). This would have increased the difficulty that Hartree and Porter would have faced when trying to follow the input curve precisely; they would have needed to contort their body to use the turning wheel and keep their eyes above the pointer device. This design increased the potential for human input error to be a variable in the accuracy rate of their analyser. In contrast, we installed the turning wheel to be in-line with the cross reticule on the Kent machine (see figure 2.12 and recheck figure 2.10 to see this part of the Kent machine in action). This allowed us to more easily follow the vertical position of the input line as the equation moved horizontally. While this change made it easier to follow the input line, we still needed to practice to ensure the highest possible level of accuracy that we could for the more complex equations, demonstrating that the accuracy rates of these machines are arbitrary and do not account for the relative skill of the operator in different contexts.

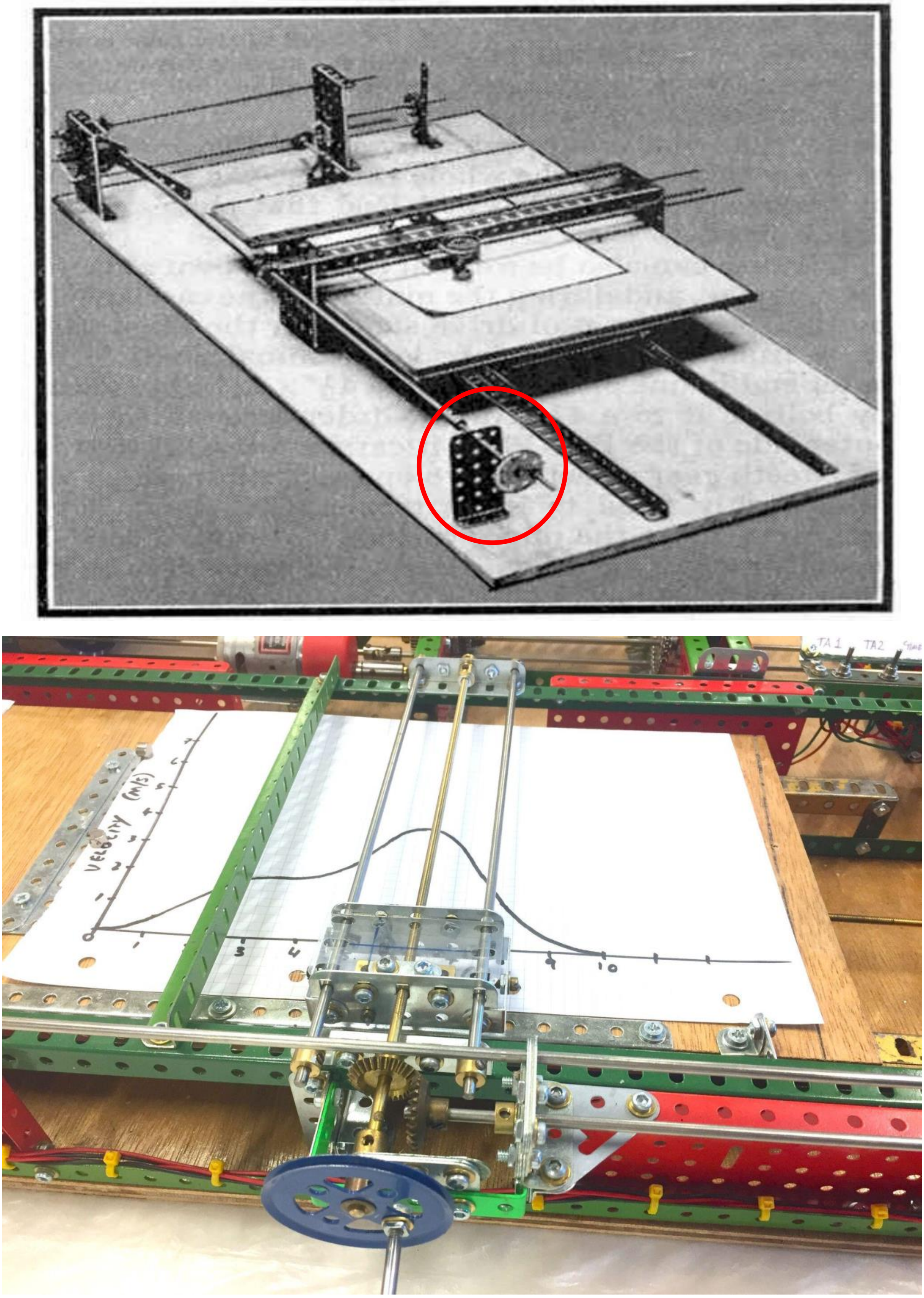


Figure 2.12: The top image is of the turning wheel on the input table of the original differential analyser, which featured in the *Meccano Magazine* in 1934. Note the location of the original turning wheel is circled in red. (Image reproduced from *Meccano Magazine*, Vol XIX, No. 6, (1934). The bottom image shows the components of the input table of the Kent machine, including the blue turning wheel. (Image taken by author).

Regardless of the input mechanism used, the relative position of the input carriage as it follows the pre-plotted curve – on vertical plane – changes the different rotation speeds of a set of lead screws and connecting shafts that drive the input integral through to the integrating unit. On both the original Meccano differential analyser and the Kent machine, the rotation speeds of these shafts would be translated into the lead screws of the integrating wheel-and-disc mechanism through sets of gearing units.[220]

To help visualise how the input table worked, this section uses the same example equation used by Hartree in the 1934 issue of the *Meccano Magazine*, and the Kent machine team when publicly demonstrating how the machine functioned in 2018-2020. This equation measures the rate of change of distance travelled by a car over a certain time period, when the car is experiencing changes in velocity. This type of equation is calculated thousands of time per second in any satellite navigation device that can be used when driving today. The input curve for this equation was a graphical record of how the velocity of the car varied over time, beginning with the car at rest. The period of time in question – say ten seconds – would have been plotted on the horizontal axis of a graph as time (s), while the changing velocity of the car would be plotted in metres-per-second (m/s) on the vertical axis. If this data was hand-computed, the rate of change would be calculated by splitting the time into separate intervals and adding up each segmented area to find the total distance covered (see figure 2.13a). In contrast, the mechanical method of the analyser provided the means to continuously

[220] These helical gearing units were not the only non-Meccano parts of the original differential analyser, which were crucial to the success of the object. For more information on this, read: Science and Industry Museum Archives, SIM 510.8, A. Porter, 'The Construction of a Model Mechanical Device for the Solution of Differential Equations, with Applications to the Determination of Atomic Wave Functions,' (MSc. Thesis, University of Manchester, 1934).

integrate this data rather than splitting it into intervals, increasing the speed and accuracy rate of the calculation (see figure 2.13b).

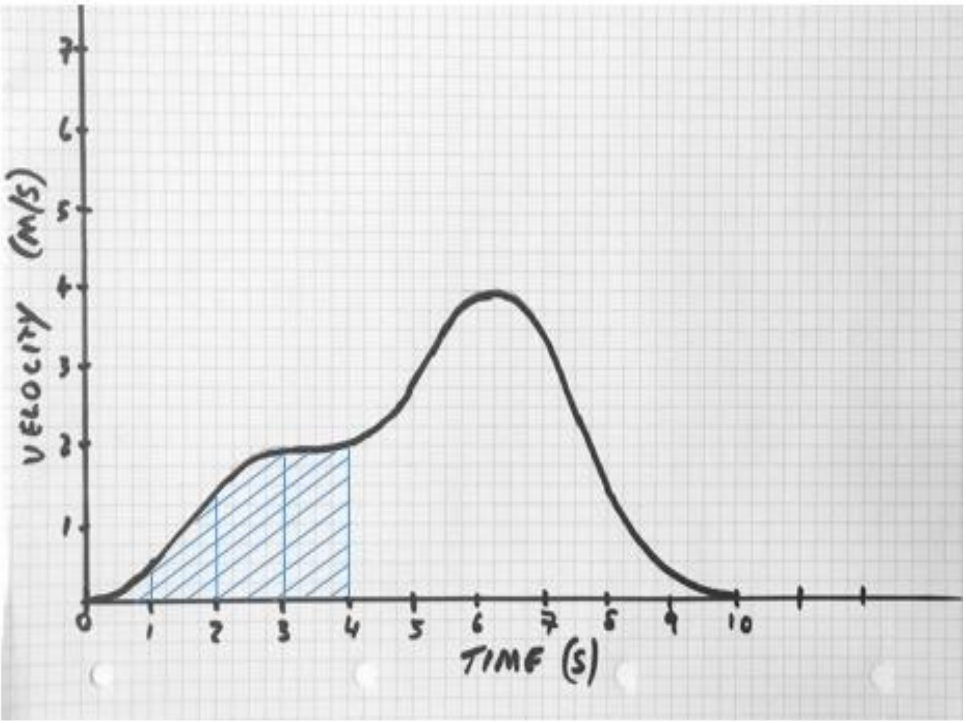


Figure 2.13a: An image that overlays sections of the graph to demonstrate how this equation would be calculated via the hand-computing method. The input graph for the differential equation measures how far a car has travelled at varying speeds over a period of time. (Image taken and edited by author).

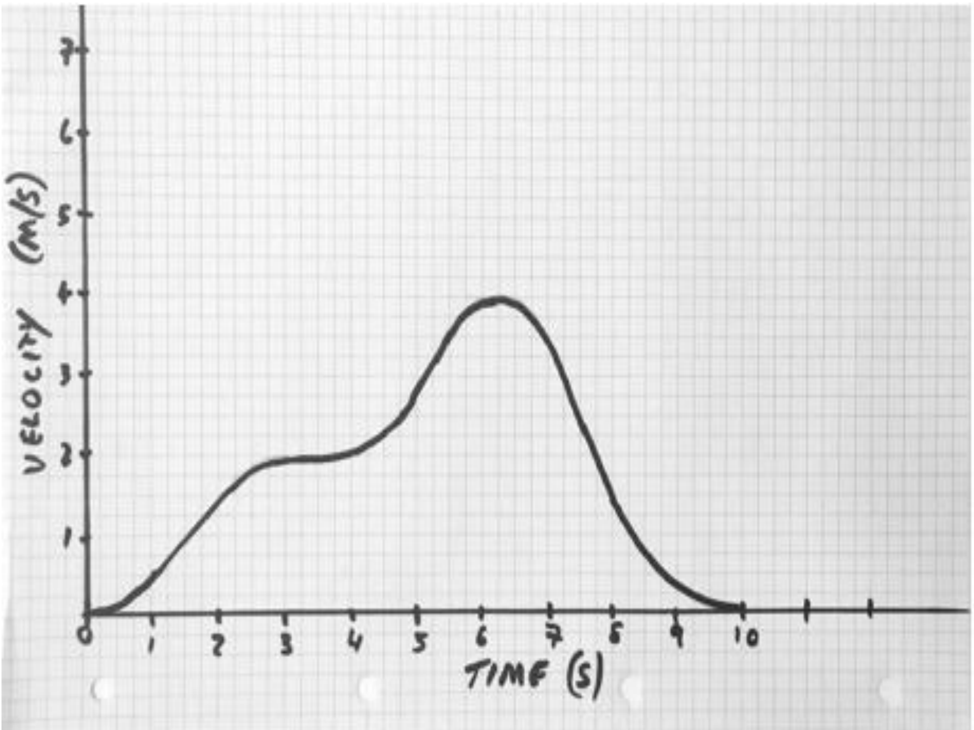


Figure 2.13b: The same image demonstrating how the differential analyser calculates the area under the graph continuously, which made it much faster than the hand-computing method. (Image taken by author).

Once these derivatives are translated into the machine, they became known as the input integral and move towards the integrating unit, via a set of lead screws.[221] The left image (of the Kent machine) in figure 2.14 demonstrates the process by which the input integral of the equation is translated from the two input screws (circled in black) into the gearing mechanisms of the analyser (circled in blue).[222] The image on the right shows the output of these gearing mechanisms (circled in blue), which then programmed a further pair of lead input screws (circled in black in the right image in figure 2.14). The rotation speed of these two lead screws represented the two derivatives of the input integral of an equation as they were translated into the integrating unit of the analyser. In both images, the component in the black circle on the left governs the rotation speed of the glass disc, while one in the black circle on the right governs the rectilinear displacement of the wheel-and-disc mechanism.

[221] I created a series of videos that demonstrate this process. They are available (along with footage from the Playful Engineering demonstration) at https://www.youtube.com/channel/UCsl0nBdDgl5_fW2ofOEX7OA [accessed 1 November 2018].

[222] The black arrows highlight the movement of the inputs, with the blue arrows used to connect the two images and help the reader orient themselves with the movement of the equation through the object.

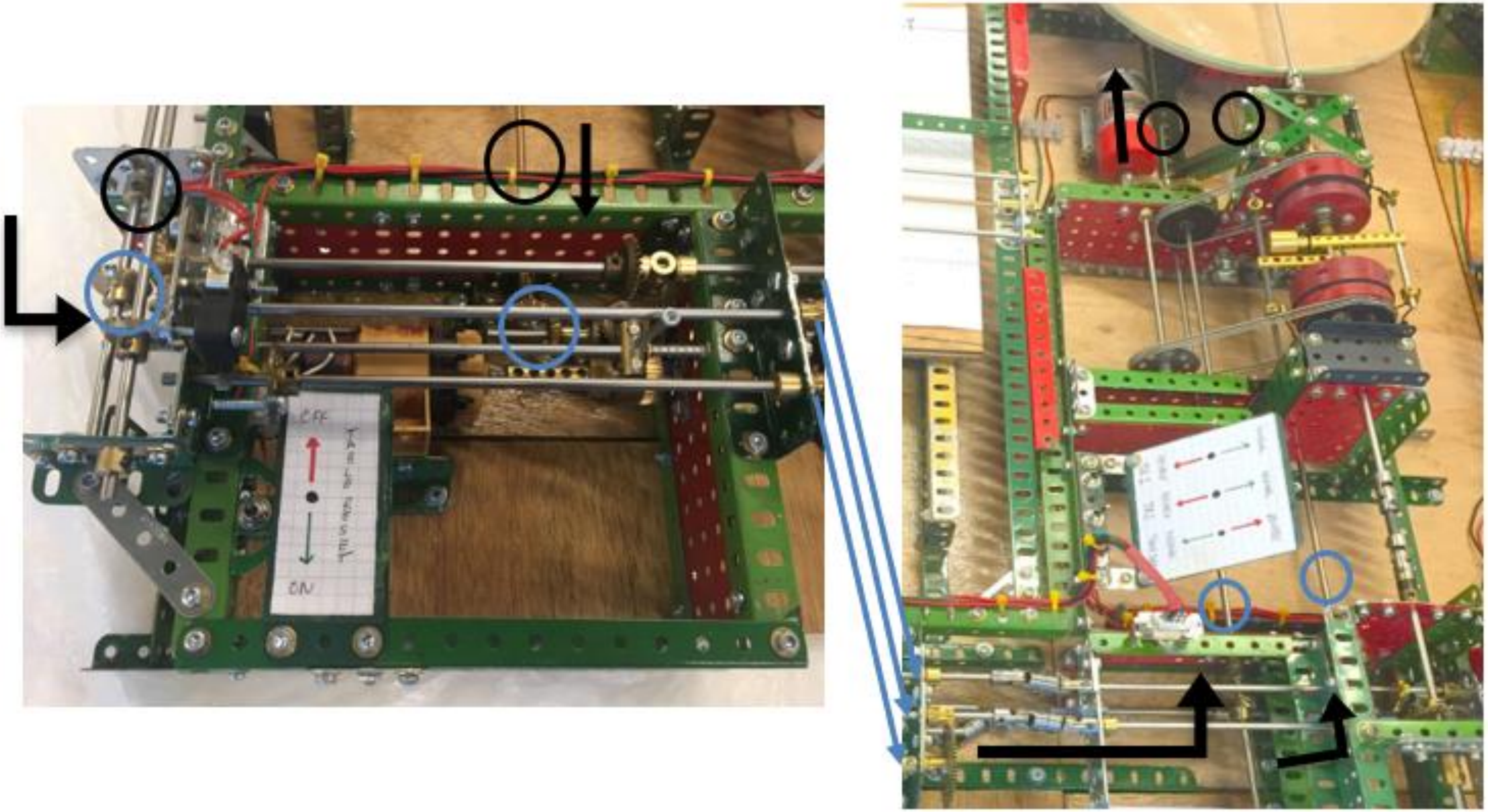


Figure 2.14: These two images demonstrate the movement of the equation from the lead screws of the input table, through a series of gearing devices to the integrating unit shown in the image on the right. (Images taken by author).

5.2. The Integrating Unit and Torque Amplifier

The integrating unit is a continuously variable gear, comprised of a steel wheel and glass disc mechanism that sits on a Meccano carriage and rails. The two lead screws programme the rectilinear displacement and rotation speed of the glass disc based on their input variables (see figure 2.15).

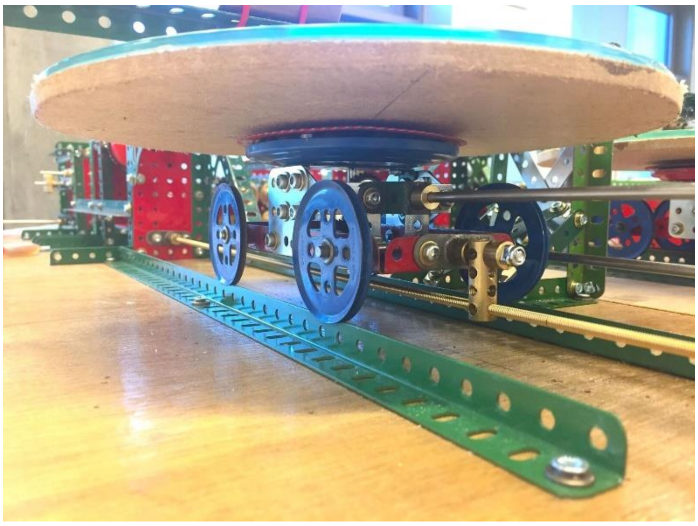
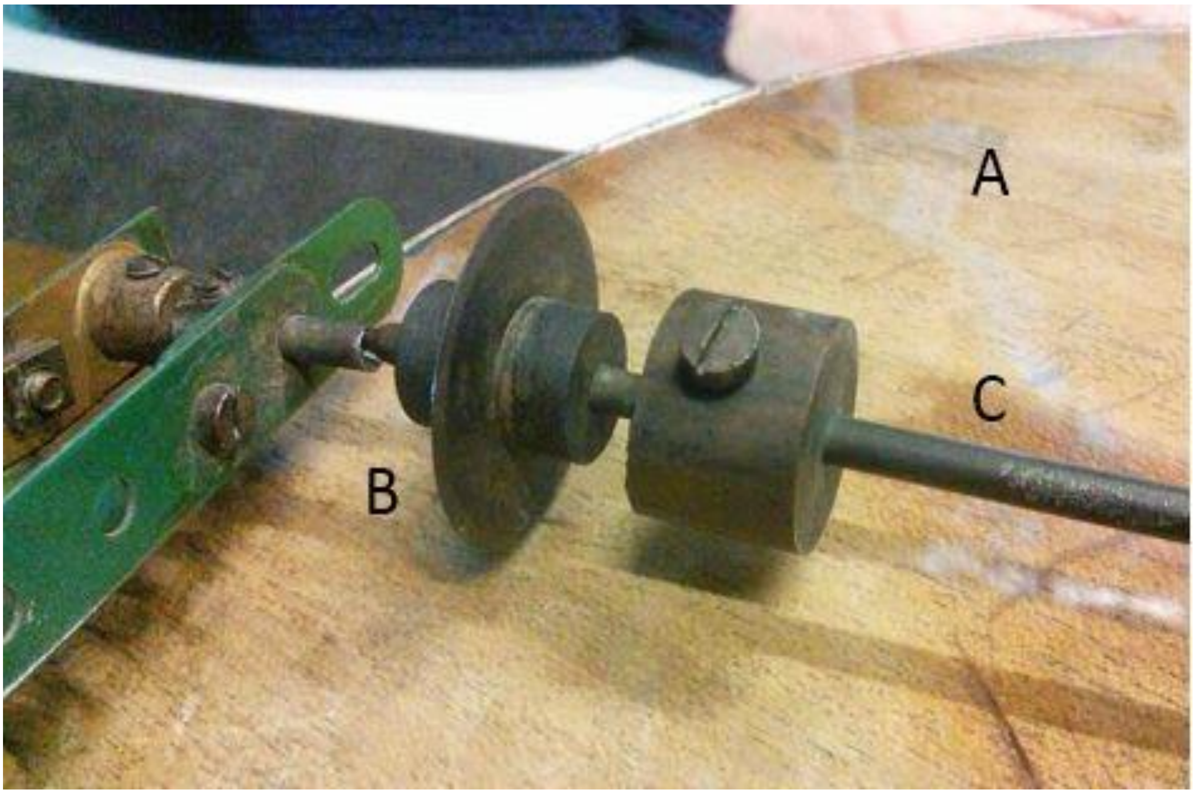


Figure 2.15: The top image shows the wheel-and-disc integrating unit on the Trainbox. (© Science Museum/Science & Society Picture Library). The bottom image demonstrates the Meccano track carriage and lead screws that controlled the rectilinear displacement and rotation speed of the glass integrating disc. (Image taken by author).

When configured for the 'circle test' equation, the two lead screws function to change the rectilinear position of the glass disc (dx^2) – the integrand – and the speed of rotation (d^2y) – the variable of integration – of the glass disc. The two movements of the integrating unit changed the rotation speed of the steel wheel that sat on top of the glass disc via friction. The steel wheel is then connected to the output integral arm, which drives the integrated equation through the rest of the machine. It is the varying speed and point of contact between the steel wheel and glass disc that represents the process of continuous integration (see figure 2.16).



A: The Glass Disk B: The Steel Wheel C: The Output Integral Arm

Figure 2.16: An image of the glass disc and steel wheel from the Trainbox. (Image taken by author).

The relative movement of the steel wheel in terms represented the value of the positive and negative numbers that featured in the equations programmed into the object. The process of integration is the result of the steel wheel rotating faster the further away it is from the centre of the glass disc, and slower as it approaches the centre of the disc (stopping at the centre, or the null point). Figure 2.17 demonstrates this, establishing that if the rectilinear movement of the disc moves the steel wheel to the A-side of the glass disc, it will turn one way, while being on the B-side would make it turn in the other direction. The relative position and speed of the steel wheel is the most important part of the process of mechanical integration in the integrating unit.

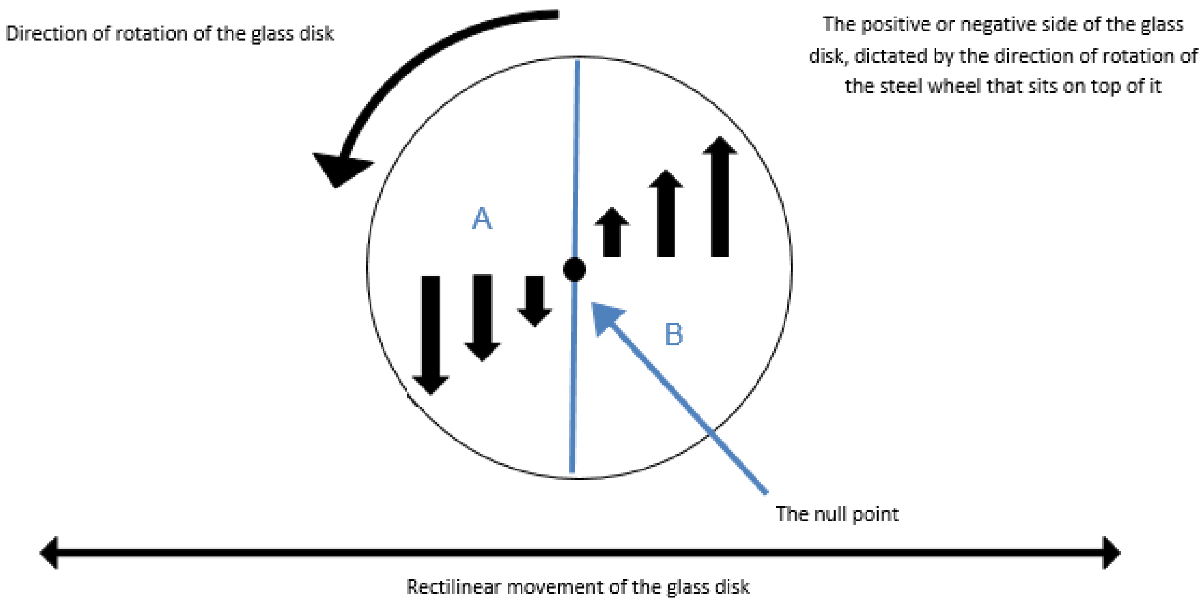
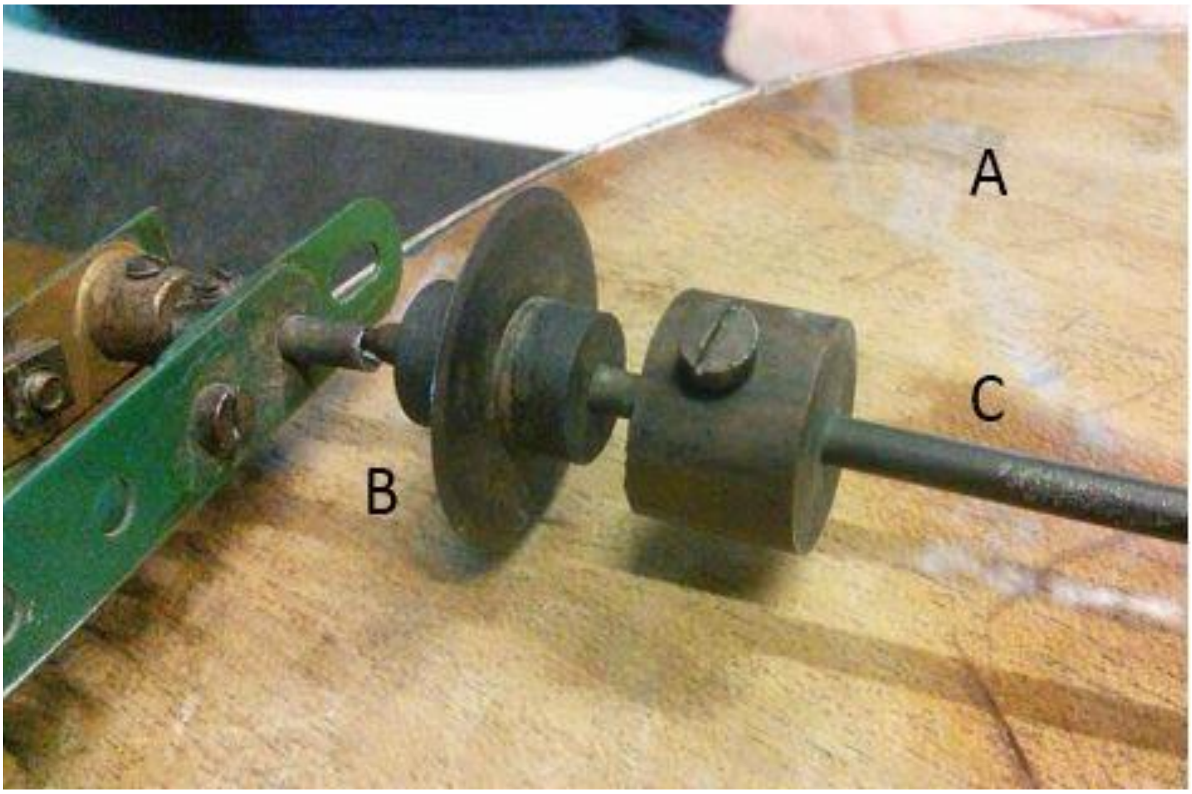


Figure 2.17: An image of how the position and rotation of the steel wheel against the glass disc changes the value it represents, demonstrating the importance of its relative position in each equation. (Image drawn by the author).

However, the small amount of friction between the glass disc 'input' and the steel wheel 'output' meant that this was also the area of the analyser that had the highest potential for mechanical inaccuracy. This inaccuracy occurs as the result of slippage in the contact between the steel wheel and glass disc, which relies entirely on friction. Hartree and Porter (and the Kent machine team) counteracted this problem by attaching brass weights on the output integral arm to ensure as much friction as possible between the two elements (see figure 2.18).



A: The Glass Disk   B: The Steel Wheel   C: The Output Integral Arm

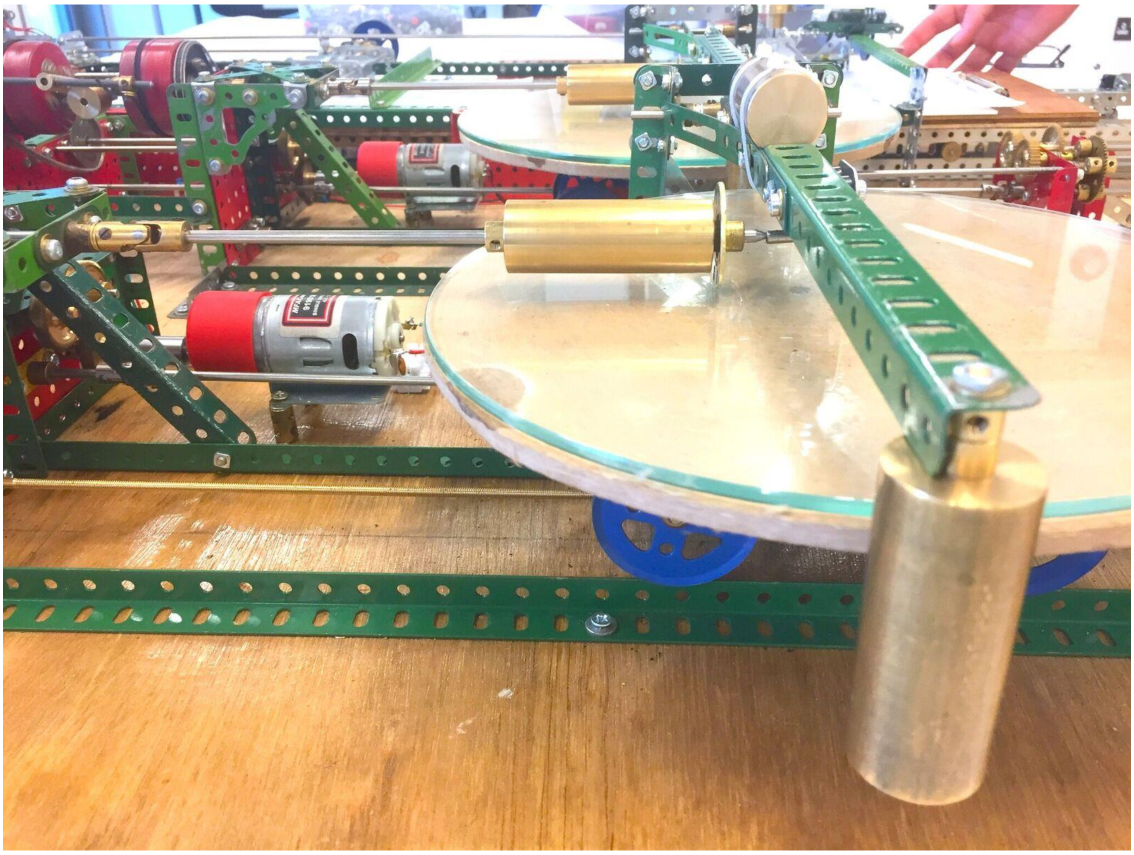
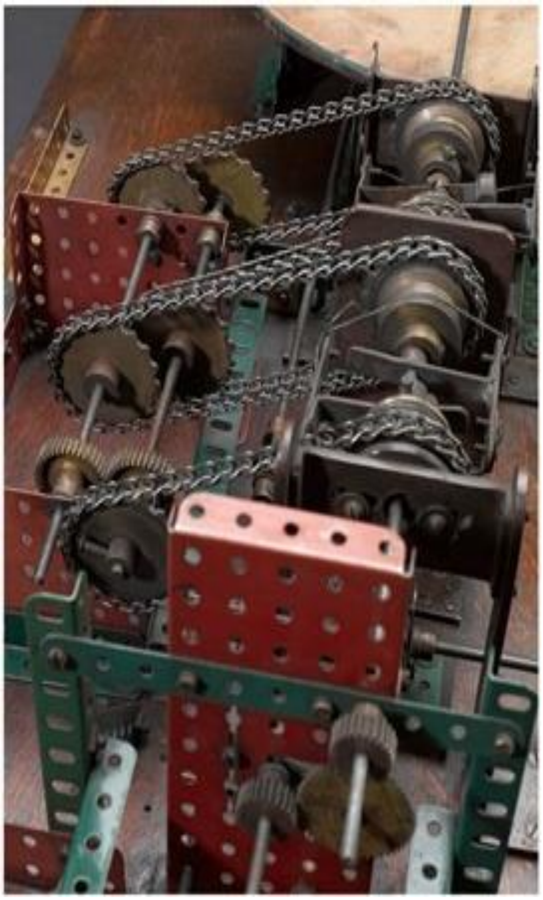
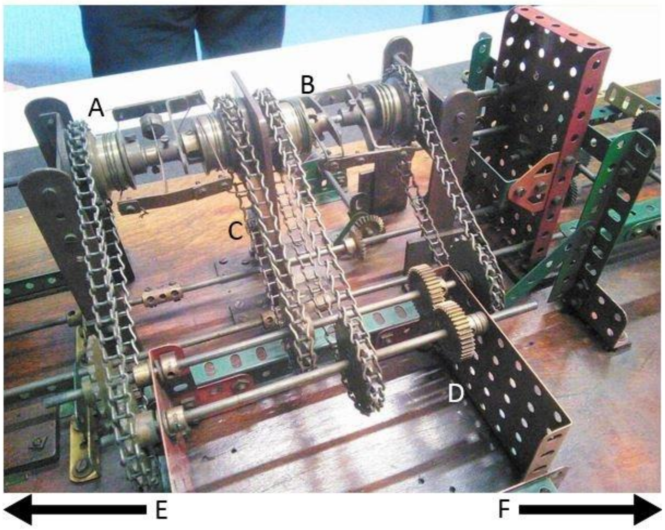


Figure 2.18: The top image is the glass disc, steel wheel, and output integral arm from the Trainbox, while the bottom image is of the same device on the Kent machine. The brass weights added to reduce slippage are clear in the centre of both images (Images taken by author).

The low amount of contact between the steel wheel and glass disc also creates a problem of low output torque on the output integral arm. If the output torque is too low, the rotations of the output integral arm could not drive the integrated equation to the subsequent units of the machine. As mentioned above, low torque was what precluded Babbage and later Kelvin and Thomson from successfully constructing their own mechanical calculating machines. Swade, in his book *The Difference Engine* (2000) confirmed that a lack of torque was an ongoing issue in the Science Museum's attempts to construct the 'Babbage Difference Engine No. 2' in the early 1990s.[223] Hartree and Porter used two 1" torque amplifiers on each integrating unit of the original differential analyser to solve this issue of low torque (see figure 2.19).





A: Input Arms of the amplifier
B: 'Capstan' Friction Drums
C: Gear Links that translate the output integral (with increased torque) to the next set of shafts
D: The gearing system that translates the integral back to the output shafts
E: The Integrating Unit is positioned to the left of the torque amplifier
F: The direction of movement of the equation towards the output table

Figure 2.19: Two images of the torque amplifiers of the original Meccano differential analyser (as they feature on the surviving Trainbox object). (Images taken by author).

[223] For more information on the challenges of torque in the Science Museum's project refer to: D. Swade, 'The Construction of Charles Babbage's Difference Engine No. 2,' *IEEE Annals of the History of Computing*, Vol. 27 (3), (August, 2005), p. 75.

The torque amplifiers increased the torque to more than 100 pound-inches (an increase of more than 2,000 times from the one ounce-inch friction that was produced by the friction between the glass disc and steel wheel on the integrating mechanism).[224] Despite Hartree asserting that the torque amplifiers 'helped to overcome the problem of low torque,' the issue of slippage and low torque continued to impact the accuracy rate of these machines.[225] The reason for this the torque amplifiers did not resolve the underlying causes of mechanical slippage. This potential for slippage between the glass disc and steel wheel continued to provide a constant challenge in these types of machines. This slippage was demonstrated in figures 2.13a and 2.13b in the accuracy section, which established that the Kent machine struggled to maintain its 99.3% accuracy rate when it was used for the same equation. Those images demonstrate that the smallest amount of slippage can drastically reduce the accuracy of the machines' automatically drawn output curve.

After the output integral of the 'circle test' ($\int y^1 dx^1/a$) passed through the torque amplifiers of the two integrators, it is translated through a series of gears and shafts into the lead screws of the output table. The rotation of these screws mirror those attached to the input table and automatically drive the relative horizontal and vertical position of the pen on the output table.

[224] V. Bush, 'The Differential Analyser,' *Journal of the Franklin Institute*, Vol. 212, (1931), pp. 447-488.
[225] D. R. Hartree, 'The Differential Analyser,' *Nature*, Vol. 136, (1935), p. 941.

5.3. The Output Table

The output table is built from a wooden panel, a bridge, a carriage, and a pen (instead of a pointer), mirroring the design of the input table. It also has an odometer that counts the revolutions of the output integral arm, providing a means of verifying the output curve. It was the movements of the output carriage that created the graphical output. The shape of the line it created would be dependent on the equation that the model was configured to integrate. It represented the cumulative rate of change of one variable of the equation as a function of another. Among the different units of the machine, the output table is the area that had the least risk of error as the output integral of an equation automatically drove the pen. Figure 2.20 contains two examples of output tables, with the top image is of the original differential analyser on the right from the *Meccano Magazine*, while the bottom image is of the Kent machine configured for the 'circle test.'

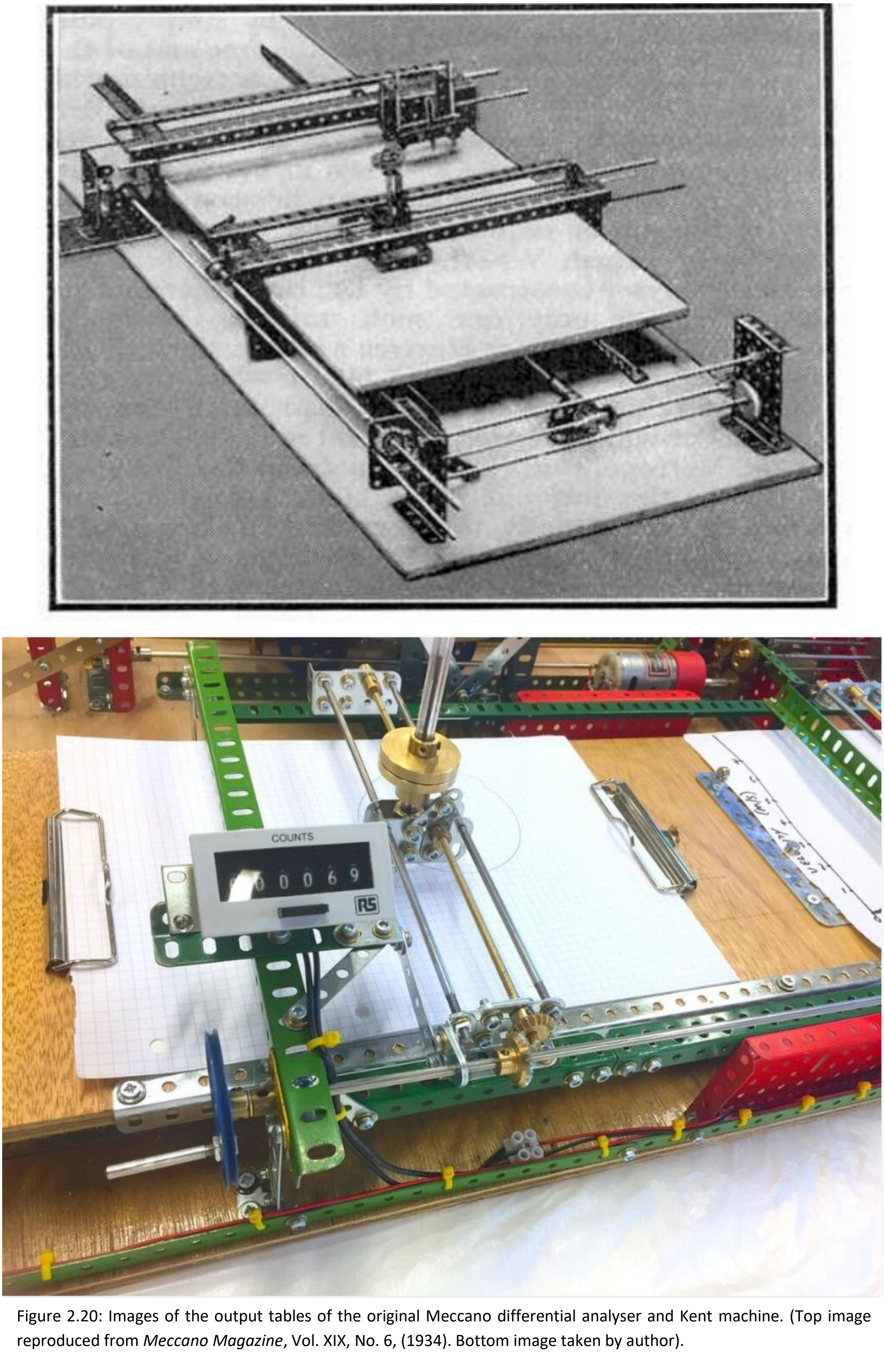


Figure 2.20: Images of the output tables of the original Meccano differential analyser and Kent machine. (Top image reproduced from *Meccano Magazine*, Vol. XIX, No. 6, (1934). Bottom image taken by author).

For the circle test, the output curve, as mentioned previously, would be a tight spiral shape. However, the output curve for the rate of change equation of the distance of the car as a function of velocity over time has also been included below to help visualise how the output curve is calculated from the input curve and movement through the different units of the machine (see figure 2.21). It demonstrates the overall distance that the car has moved in this ten second period. The axes of this output graph are similar, with time (s) still on the horizontal axis, and distance in metres (m) on the corresponding vertical axis in velocity (m/s). The shape of the curve corresponds to the initial increase and decrease in velocity, with higher velocities relating to a steeper output curve and lower velocities equating to the 'levelling off' of the line as the distance that the car is travelling no longer increases. The line demonstrates that the distance that the car has travelled increases in relation to the relative velocity of the car, before levelling off at 21 metres after ten seconds.

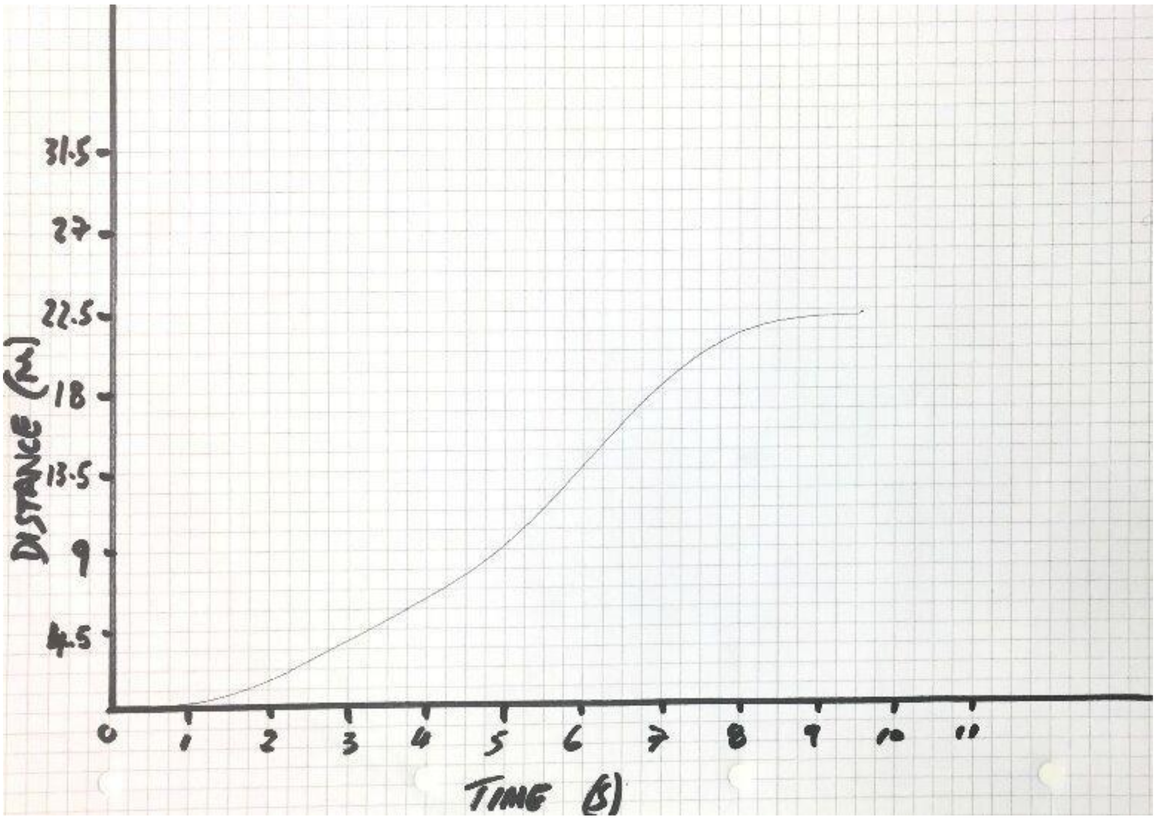


Figure 2.21: The output graph for the differential equation that measures how far a car has travelled at varying speeds over a period of time. The differential analyser has calculated that the car travelled 21 meters in the ten second time period. (Image produced and photographed by author).

The different parts of this section have focused on the 'nuts and bolts' workings and connections between each unit of the original differential analyser and Kent machine, building on the mathematical and conceptual detail and presumed knowledge that characterises Crank's and other's descriptions of these machines and their functionality. This approach has demonstrated the importance of the human input that was required to operate the machine for different equations and highlighted the arbitrary nature of the 98% accuracy rate attributed to Hartree and Porter's analyser from the 'circle test.'

6. The 'Mechanical Marvel'

The June 1934 issue of the *Meccano Magazine* contained three articles on the differential analyser.[226] In comparison to Hartree and Porter's 'demonstration model,' these articles focused less on the mechanical method of the analyser as a solution to the challenges of hand-computing, except the third that Hartree assisted in writing. This section will compare the 'nuts and bolts' realities of Hartree and Porter's Meccano analyser established in the previous section with the 'Mechanical Marvel' presented in the magazine. It will explore how material and immaterial aspects of the analyser were subject to 'Meccano-fication,' a process that was used to make complex models relevant for readers of the *Meccano Magazine*. Although the academics who built and used these machines were unlikely to read the *Meccano Magazine* to understand its capabilities, these articles are examples of how the machine was presented and understood in contrast to the realities of the mechanical method.

Each of the three articles in the *Meccano Magazine* presented the analyser in a slightly different way, beginning with the first, which had the title 'Meccano Aids Scientific Research.' The article called the analyser a 'Mechanical Marvel,' referring to its mathematical function and mechanical method in a single sentence. It described how the mechanism could 'automatically resolve complex mathematical problems with uncanny speed and accuracy.'[227] However, the previous section established that the analyser could not automatically resolve problems and required a significant amount of human input to function. The notion of 'uncanny speed and accuracy' is slightly less problematic, as compared to other methods available in 1934, the analyser would have been much quicker and 'accurate enough.' Nevertheless, this presentation still hides the challenges of the mechanical method and the

[226] *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), pp. 441-444.
[227] E. Hawks, 'Meccano Aids Scientific Research,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 441.

fact that equations with higher complexity would take much longer to programme, calibrate, and resolve, which would reduce the accuracy rate and usefulness of these types of analogue machines.

The title of this first article - 'Meccano Aids Scientific Research' – reflects this version of Meccano, which reduced the complexity of concepts to present them as things within the grasp of the Meccano boy readers. The article did this by stating that the analyser was a Meccano model of Bush's original machine, rather than a mathematical machine in its own right. It also emphasised Hartree's decision to use Meccano, painting him as a professional scientist, for whom, using Meccano was 'natural' as it 'had provided him with many happy hours when he was a boy.' This particular presentation of the analyser and Hartree ignored the role of Porter entirely. The purpose of these changes appears to have been to place less focus on the concept of mechanical integration (and its challenges), and instead, highlight the infinite possibilities of the 'ready-made parts [of Meccano] with which almost any mechanical movement can be reproduced.' This along with the use of the term 'Mechanical Marvel' further demonstrates that Meccano was intended to represent an aspirational emblem of fan-participation in international science and engineering during this period. The final paragraph of this short article then doubled down on this presentation with the statement that the results 'Hartree had already achieved with the model are sufficient in themselves to justify the claim that the model represents the most remarkable scientific application of Meccano parts that has yet been made.'[228]

The second article on the analyser presented the analyser differently, evidenced by its title, 'Are Thinking Machines Possible?' Instead of focusing on how Meccano had been used,

[228] Ibid., p. 441.

the article discusses how the 'The triumph of the Bush Differential Analyser and of its Meccano counterpart' represent the transition from 'muscular effort to mechanical power.' It describes how mechanical machines 'are constructed in such a way that they are practically free from error,' and how they are 'capable of processes equivalent to a mechanical type of thinking.'[229] This presentation of the original differential analyser as a juxtaposition to 'muscular effort' does not reflect the realities and challenges of the mechanical method, or how human operators were still a crucial part of the process. Of all three articles in the magazine, this is perhaps the most interesting one as it drastically overestimates the capabilities of the machine. While it is different from the first article, the object is still described in an aspirational way, with the description that it was something 'practically free from error' appearing to misunderstand how the analyser worked at a physical level. A potential explanation for this presentation is that the mechanical method had many fewer errors when compared to the hand-computed method, and that therefore, it was considered to be much more accurate than compared to its predecessor. However, the analysis of the problems with each unit in the previous sections demonstrates the challenges with this statement.

The longest article of the three – 'Machine Solves Mathematical Problems: A Wonderful Meccano Mechanism' – was written with assistance from Douglas Hartree.[230] His influence is clear as the article describes the mathematical function of the analyser using terms similar to his 1934 'demonstration model' article. In comparison to the previous two articles, Porter's role in building the analyser features, alongside a lengthy example of how it functioned, and an example equation that it could be used to resolve. However, while this

[229] E. Hawks, 'Are Thinking Machines Possible?,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 441.
[230] E. Hawks, and D. R. Hartree, 'Machine Solves Mathematical Problems: A Wonderful Meccano Mechanism,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), pp. 442-444.

article is much closer to the 'nuts and bolts' realities of the machine, it still simplifies the analyser and places an emphasis on its Meccano form over its instrumentality. An example of this is 'Professor Hartree is finding it of great value in connection with his research on electrical problems connected with the constitution of the atom, and thus Meccano is playing an important part in an interesting field of scientific work.' This emphasis on Meccano is further pronounced in the second half of the article, which punctuates Hartree's explanations of the processes of integration with references to the specific Meccano pieces that were used in each unit of the object:

> The cross shaft from the appropriate longitudinal shaft is journalled [sic] at its outer end in one of the holes in a 4½" x 2½" Flat Plate held vertically by bolting it to a 4½" Angle Girder screwed in the table. On the outer side of the Flat Plate it carries a pinion that indirectly drives a 57-teeth gear wheel, in two opposite outer holes of which are Axle Rods firmly fixed to it by means of Collars.[231]

It is interesting that in contrast to this article, Hartree never addressed the use of Meccano in any great detail in his publications, beyond stating that he had used it to build the original differential analyser. Therefore, the various presentations of Hartree and Porter's 'demonstration model' as a 'Mechanical Marvel' corresponds to the 'Meccano-fication' that characterised Hawks' tenure with Meccano and the Meccano Magazine. This practice is

[231] E. Hawks, and D. R. Hartree, 'Machine Solves Mathematical Problems: A Wonderful Meccano Mechanism,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 444.

apparent when comparing the image of Hartree and Porter's 'demonstration model' with the 'Mechanical Marvel' in the *Meccano Magazine* (see figures 2.22a and 2.22b).

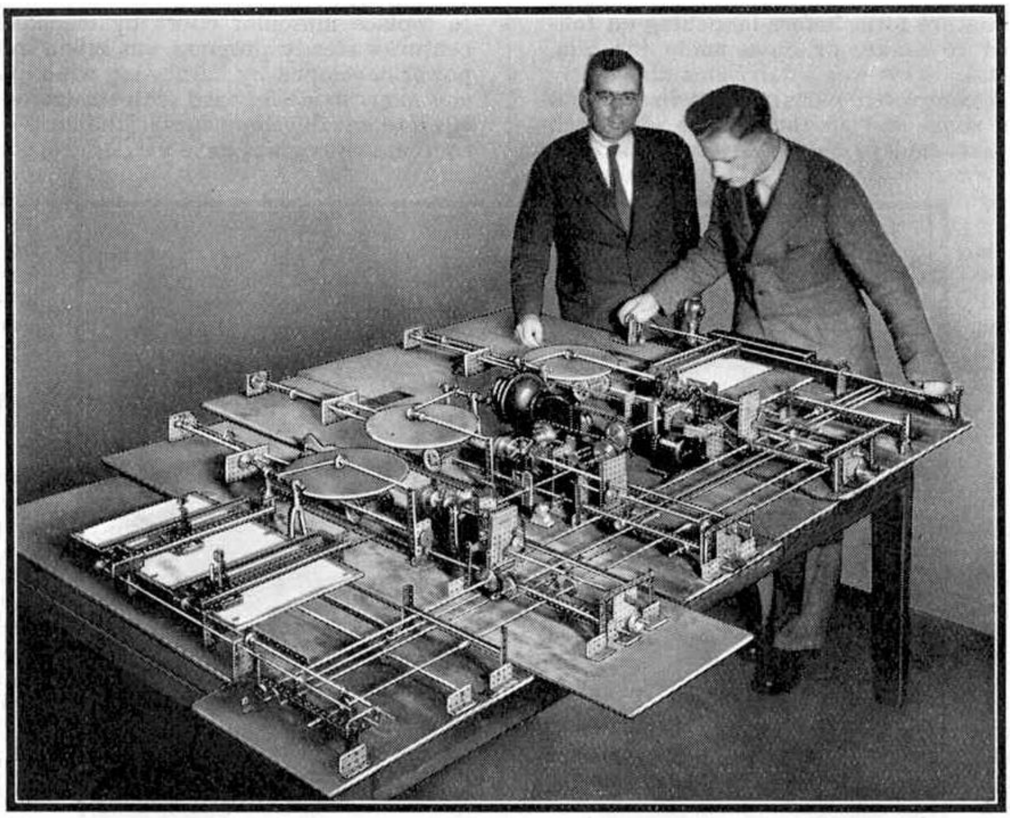


Figure 2.22a: The original image of the Meccano differential analyser constructed by Hartree and Porter in 1934. (© Science and Industry Museum, Informal Collection).

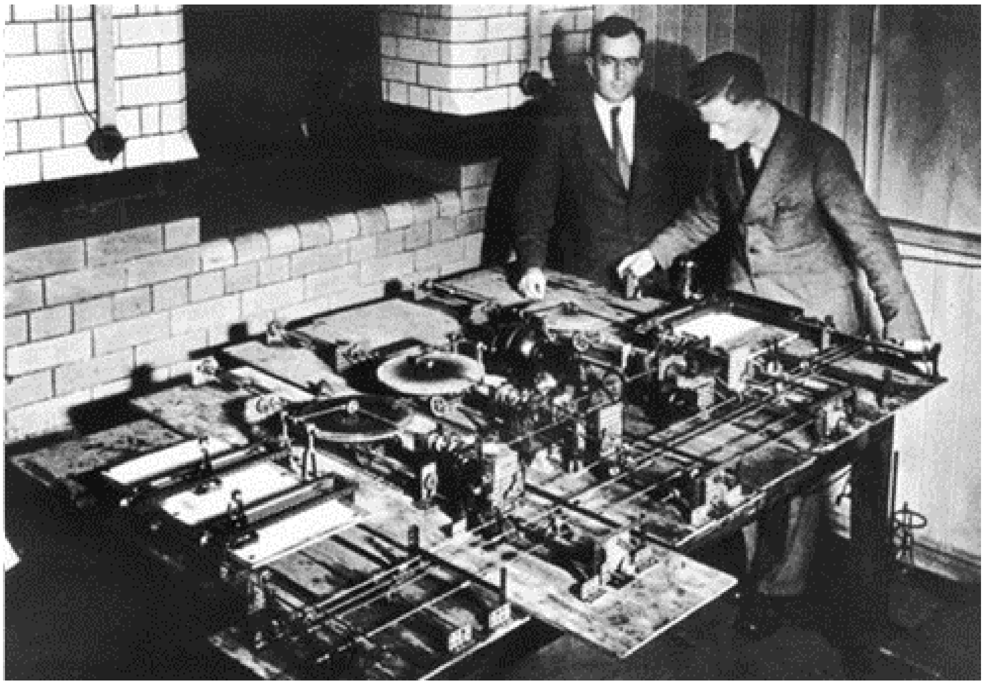


Figure 2.22b: An image that demonstrates how the original was manipulated and changed by the *Meccano Magazine* to make it appeal more to their readers, focusing more on the Meccano components of the object. (Image from the *Meccano Magazine*, Vol. XIX, No. 6, (1934)).

The contrast between these two images highlights how the magazine presented the analyser in a way that allowed it to capitalise on the fact that it was made from Meccano, instead of exploring its utility as a mathematical object. However, while the practice of ‘Meccano-fication’ simplified complex machines to bring them within reach of readers, it also resulted in images of the machine where aesthetics trumped reality. The technique of ‘Meccano-fication’ is a well-known part of magazine folklore amongst contemporary Meccano enthusiasts, who have also pointed out other less intentional examples of the how magazine’s attempts to simplify led to impossible objects. When the issue of ‘Meccano-fication’ was discussed with Meccanoman Matt Goodman, he replied, ‘OH YES, the Meccano Block Setter! They did that all the time.’[232] Matt’s comments referred to an image from the front cover an instruction manual for a Meccano Outfit No. 6, which was released in 1948 (see figure 2.23). The crane in the image contained pieces of Meccano that did not actually exist; the Meccano pieces in the crane has an even number of holes, while Meccano pieces always have odd-numbered holes in their struts to ensure that there was a central point. He explained that the users became more aware of these flaws in the 1940s and 1950s, but that this was a particularly fun example, as the boy’s hand is simultaneously in front of and behind of the same pieces of Meccano.

[232] Matt Goodman, personal communication, 9 October 2018.

Figure 2.23: This image of a Meccano Block Setting Crane is famous among Meccano enthusiasts as it depicts an impossible model, built with non-standard Meccano parts (that did not exist at the time) and the boy's hands contorted in a way was also not possible. (Image reproduced from Meccano Instruction Booklet for Outfit No. 6 (1948)).

The negative impact of this 'Meccano-fication' is more obvious in the image of Porter's proof-of-concept model that featured in the magazine. In the image, the entire upper left quadrant of the image has been redrawn (the tracing lines are still visible), meaning that there were various rods, gears relating the scaling factors, and other elements that were floating and unconnected to the rest of the object (circled in green). In the bottom left quadrant of the image, the turning wheel – that governed the movement of the input table – is not connected to any other part of the object (circled in red), and is situated in-line with the input bridge, a design feature that did not appear in any of other images of Hartree and Porter's input table designs (see figure 2.24).

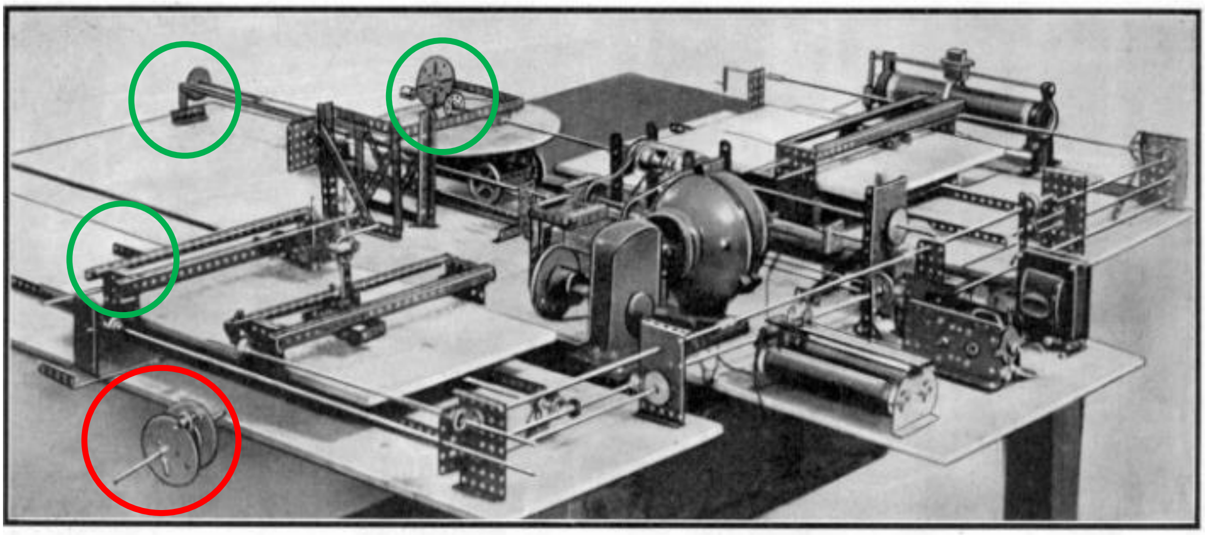


Figure 2.24: An image of Porter's initial proof-of-concept model – that featured in the *Meccano Magazine* – contains a series of omissions, changes, and mistakes that mean the object would not be able to work. (Image reproduced from *Meccano Magazine*, Vol XIX, No. 6, (1934)).

The changes made to Hartree and Porter's 'demonstration model' are significant as the magazine claimed to be presenting an actual scientific accomplishment made of Meccano ('the most remarkable scientific application of Meccano parts that has yet been made').[233] Yet these changes demonstrate that to support the magazine's presentation of the object as a 'Mechanical Marvel,' the presentation of the analyser overlooked the realities and mechanical drawbacks of the mechanised method.[234] This type of disjuncture between the 'nuts and bolts' of the machine and its presentation as a 'Mechanical Marvel,' was also reflected elsewhere with *The Observer* stating that with the completion of the Manchester machine, '...man was being supplanted by robots, and job security would be threatened,' on 31 March, 1935.[235] These presentations of the analyser – with accuracy rates that did not account for human-induced errors and that ignored the mechanical realities of the machine – inflated the capabilities and expectations of these machines in the years before the Second World War.

[233] E. Hawks, 'Meccano Aids Scientific Research,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 441.
[234] E. Hawks, 'Meccano Aids Scientific Research,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 441.
[235] Anon., Comment on the Manchester machine featured in 'At Random' section, *The Observer*, (31 March, 1935).

7. Conclusion: Circles and Changing Contexts

This chapter has explored the material and immaterial aspects of the differential analyser to try and understand the differences between the realities and presentations of this complex machine. It has demonstrated that the mechanical method of the differential analyser – despite its deficiencies – did initially equip mathematicians with a useful tool to approach and solve more complex differential equations than they had been able to achieve with previous methods.[236] However, it also explored the tension between the different presentations of the machine both as Hartree and Porter's 'demonstration model' and the *Meccano Magazine*'*s* 'Mechanical Marvel,' and the 'nuts and bolts' realities of the analyser. It has highlighted how both Hartree and Meccano presented the object in different ways to make it satisfy the aims they had for their respective audiences. It established that for Hartree, the value of the Meccano differential analyser was as a model that demonstrated the mechanical method clearly and simply, while also exceeding expectations and 'resolving' the challenges of hand-computed equations. In contrast, it demonstrated that in the *Meccano Magazine*, the object was subjected to the processes of 'Meccano-fication,' which changed both material and immaterial aspects to support the version of Meccano that existed in this period. These analyses provide a better understanding of the machine, and perhaps why the machine changed from Porter's description of something 'almost miraculous' before the war, to Crank's post-war assertion that it was a mathematical 'object of last resort.'

The context, accuracy, and 'nuts and bolts' exploration of the differential analyser demonstrated that the accuracy rate of these machines was entirely arbitrary as they

[236] However, there were still a number of exponential, radical, logarithmic, and trigonometric functions that the differential analysers could not be used to integrate. These functions cannot be integrated because the variables of the equation cannot be separated, requiring the use of a different methodological approach, reducing the usefulness of the object further.

depended on the accuracy of both humans and computers in conjunction with each other. It also highlighted that the accuracy rate was contingent on the variable level of human skill in configuring and programming each specific equation. This meant that compared to claims that the machine could solve previously 'unsolvable' equations, the accuracy rate for more complex equations began to be negatively correlated as operator's 'accuracy bias' with the 'circle test' was exposed.[237] The challenges of the mechanical method meant that as the requirements for more complex equations increased in the later years of the 1930s, so too did the number of integrators that were required to resolve the variables of the equation. Compared to Hartree and Porter's Meccano machine, the Rockefeller Differential Analyser weighed over 100 tons and was comprised of eighteen individual integrating units, 200 miles of wire, and thousands of mechanical components, all of which had to be calibrated and configured for each different equation.[238] Despite increased application, this dramatically increased the risk of both human-induced, and mechanical errors, which helps to explain why Crank and others began to move away from their use as research objects during the Second World War.[239]

Despite the challenges of their 'nuts and bolts' mechanical method, the next chapter will establish that differential analysers were still among the most powerful and useful calculating machines available during the war. It brings together the stories of these machines in one place for the first time, providing a new set of case studies to add to the changing relationship between analogue and digital computers in the history of computing literature.

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[237] Science Museum Archives, Sc. M. 1949-134/3.Anon., 'Most Wonderful Machine In Europe Made From Toy,' *News Chronicle*, (8 February 1935).

[238] L. Owens, 'Vannevar Bush and the Differential Analyser: The Text and Context of an Early Computer,' *Technology and Culture*, Vol. 27 (1), (1986), pp. 63-95.

[239] For more on the story of this and other large analogue computers, refer to: V. Bush, "Arithmetical Machine," reprinted in B. Randell (ed.), *Origins of Digital Computers: Selected Papers, (*Springer-Verlag, Berlin Heidelberg, 1982), pp. 337-344; M. Hally, *Electronic Brains: Stories from the Dawn of the Computer Age,* (Joseph Henry Press, 2005); and W. G. Walter, *The Living Brain,* (Norton, 2013).

The analysis of each object will help to explain more about how they functioned and demonstrate that while these machines were used less for research purposes, they remained ‘accurate enough’ to be used for modelling and teaching purposes for decades after the war. The stories of these other British differential analysers will provide case studies for the history of computing to further challenge the ‘analogue gap,’ as well as context for Hartree’s decision to save pieces from the original differential analyser and turn them into Trainbox model in 1947, which was collected by the Science Museum in 1949.

Chapter Three – Objects, Uses, and Contexts: The Applications of British Differential Analysers before, during, and after the Second World War

1. Introduction

Larry Owens' 'Where are we going, Phil Morse?: Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957' (1996), expressed discontent with the linear history of computing. Owens asserted that that contrary to what historians have written, 'we have not yet begun to understand the history and significance of analogue computing, especially the relationship between analogue and digital machines.'[240] Small's *The Analogue Alternative, The Electronic Analogue Computer in Britain and the USA, 1930-1975* (2001) made a case for the history of computing that did not view analogue and digital as linearly-related technologies. He asserts that a gap exists in how computing has been written about and understood since the Second World War.[241] David Mindell answered Small's call in *Between Human and Machine* (2002), where he asserted that 'analogue and digital arose together, as distinct but related approaches to representing the world in machines.' He asserted that 'in general, historians of computing have neglected analogue computing, viewing it as an obsolete predecessor to digital…an obstacle to be overcome, and source of resistance to the new, inevitable digital techniques.'[242] However, while this argument is well-established in the academic history of computing today, the 'analogue gap'

[240] L. Owens, 'Where are we going, Phil Morse?: Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957,' *IEEE Annals of the History of Computing*, Vol. 18 (4), (Oct-Dec, 1996), p. 40.
[241] J. Small, *The Analogue Alternative, The Electronic Analogue Computer in Britain and the USA, 1930-1975* (Routledge, 2013), p. 1.
[242] D. A. Mindell, *Between Human and Machine: Feedback, Control, and Computing before Cybernetics* (Johns Hopkins University Press, 2002), p. 10.

persists in both popular histories and museum contexts.[243] A potential reason for this is that in making their arguments, Owens, Small, and Mindell predominantly focus on American analogue machines rather than the changing role of British differential analysers before, during, and after the Second World War.

Therefore, the first aim of this chapter will be to explore the stories and applications of the British differential analysers constructed before, during, and after the Second World War. It will demonstrate that while the original Meccano analyser was not used during the Second World War, the analogue method inspired many other scientists, mathematicians, and amateurs to build their own Meccano and non-Meccano variants that were applied to significant projects during and after the war. This chapter goes onto discuss the various contexts of the original differential analyser, at the University of Manchester, the and at the Science Museum, as well as its different identities, as a 'Mechanical Marvel,' a 'demonstration model,' and the Trainbox. The analysis in this chapter further demonstrates the complex nature of this object and how it challenges the traditional understanding of Meccano, models, mathematics, and computing. The use of these objects, as research instruments, mathematical machines, or teaching tools will be considered, along with their identities as mathematical, scientific, engineering, or computing objects. These analyses will further help to reduce the 'analogue gap,' and answer the questions of 'what were the applications of these machines?' and 'do they change our understanding of what a computer is?'

Through adopting an approach that focuses on their benefits, rather than their drawbacks in relation to digital methods, this chapter will establish that similar to other analogue machines, larger British differential analysers were developed in parallel to digital

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[243] Chapter Four uses the Science Museum's exhibition of Hartree's Trainbox object to explore the 'analogue gap' further. It demonstrates the object has been ventriloquised with different voices to make it fit into the traditional story of digital computing.

methods, and that smaller differential analysers were increasingly used for teaching purposes. As well as providing further case studies for this approach to the history of analogue and digital computers, these stories will help to re-contextualise Hartree's decision to use Meccano pieces from the original differential analyser to build the Trainbox as a teaching device in 1947.

The second section tells the stories of the 'primary' differential analysers that the Meccano model inspired. These include the Manchester machine, the Cambridge Meccano model, and the Cambridge machine. Each subsection focuses on the different applications of these analysers before, during, and after the Second World War, as well as the teams (or 'job shop') that operated them. These stories will demonstrate that despite their apparent failings/limitations, their various applications were crucial to the British war effort; including the Tube Alloys project, sub-harmonics, ballistics, and the problems of automatic firing mechanisms.

The third section tells the stories of the other 'secondary' differential analysers constructed before and during the war.[244] It discusses how differential analysers are not a homogenous group of objects, but were constructed by enthusiasts for specific purposes, such as Beard's machine for the Institute of Financial Actuaries, or 14-year-old William Worthy's Meccano model, which were both used as teaching devices. It also considers examples of larger machines that were constructed before, during, and after the war to show how this type of analogue technology continued to develop in parallel to digital.

[244] I have chosen the designations of 'primary' and 'secondary' to distinguish between the levels of evidence that are available for the machines and their uses through the Second World War, rather than a judgement of their relative importance to the British war effort.

2. Primary Differential Analysers in Britain

The previous chapter discussed the original Meccano differential analyser at length, explaining that despite being initially designed as a proof-of-concept model, the original differential analyser was used in 1934 and 1935 to resolve the atomic wave functions for many different atoms, including potassium, caesium, nitrogen, and sodium.[245] However, as the war approached, the shortcomings of the original Meccano model analyser resulted in it being used for lower-order equations and exploratory work, before Hartree took it home with him in 1939. In a conversation shared with Hartree's son Richard, he explained that he remembered the Meccano analyser sitting in his father's study in Manchester at the beginning of the war and that it was still there when the family moved to Cambridge in 1946.[246] In Froese Fischer's book, Richard also described his memories of his father 'tinker[ing] with the analyser ... from time to time,' before he and his siblings were evacuated to the University of Toronto from 1940 to 1944.[247] His recollections suggest that Douglas used the original differential analyser at home during the war.

Despite this, no documentation exists for the Meccano analyser being used during the war, and it does not feature in any of Hartree's published works after 1936, except for a single paragraph in his post-war report on the wartime applications of the machines, *Differential Analyser: On the work of the S. R. A. Group*. In it, Hartree described how the unexpected success of the original Meccano analyser in 1934 and 1935 had inspired the creation of the

[245] D. R. Hartree, 'Results of Calculations of Atomic Wave Functions II – Results for K and Cs,' *Proceedings of the Royal Society,* Vol. 143 (850), (London, 1934), pp. 506-517; D. R. Hartree and W. Hartree, 'Self-Consistent Field, with exchange for Nitrogen and Sodium,' *Proceedings of the Royal Society,* Vol. 193 (1034), (London, 1934), pp. 299-304; and D. R. Hartree, and W. Hartree, 'Results of Calculations of Atomic Wave Functions III – Results for Be, Ca and Hg,' *Proceedings of the Royal Society,* Vol. 149 (867), (London, 1935), pp. 210-231.
[246] Richard Hartree, personal communication, 24 October 2018.
[247] C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific Publishing, 2003), p. 23.

Manchester machine, but does not include any wartime applications.[248] While photographs and short descriptions of the original Meccano analyser do appear in Hartree's *Calculating Instruments and Machines* (1949), this book does not directly discuss the applications of the analyser or its Meccano materiality. Instead, it focuses on development and application of the Meccano analyser's successor, the larger Manchester machine, which was used to resolve the more complex, partial-differential equations.[249]

Therefore, despite Hartree and Porter adding a fourth integrating unit to the Meccano analyser in 1935 (increasing the order and complexity of the equations that it could be used to resolve), a series of newly constructed analysers soon superseded it (see figure 3.1). It is these analysers that are considered in the following subsections. They will demonstrate how the applications of these three primary analysers changed before, during, and after the war, and how each came to be used more for experimental modelling purposes that supported the development of newer analogue and digital machines, rather than directly dealing with more complex equations. Taken together, these stories provide case studies that contrast with previous explanations of how analogue machines were used during the Second World War, and how they contrast to their identities in museums today.

Date	Constructor(s)	Materials	Location	No. of Integrators
1934	Hartree and Porter	Meccano	Manchester University	3 (4)
1935	Lennard-Jones, Wilkes, and Bratt	Meccano	Cambridge University	5
1935	Metropolitan Vickers	Non-Meccano	Manchester University	4 (8)
1939	Metropolitan Vickers	Non-Meccano	Cambridge University	8

Figure 3.1: A table of the differential analysers constructed at the University of Manchester and Cambridge before the Second World War. The numbers in parentheses indicate the final number of integrators on each machine (Data collated by author).

[248] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946), p. 80.
[249] D. R. Hartree, *Calculating Instruments and Machines* (University of Illinois Press, 1949), pp. 10-15.

2.1. Manchester machine

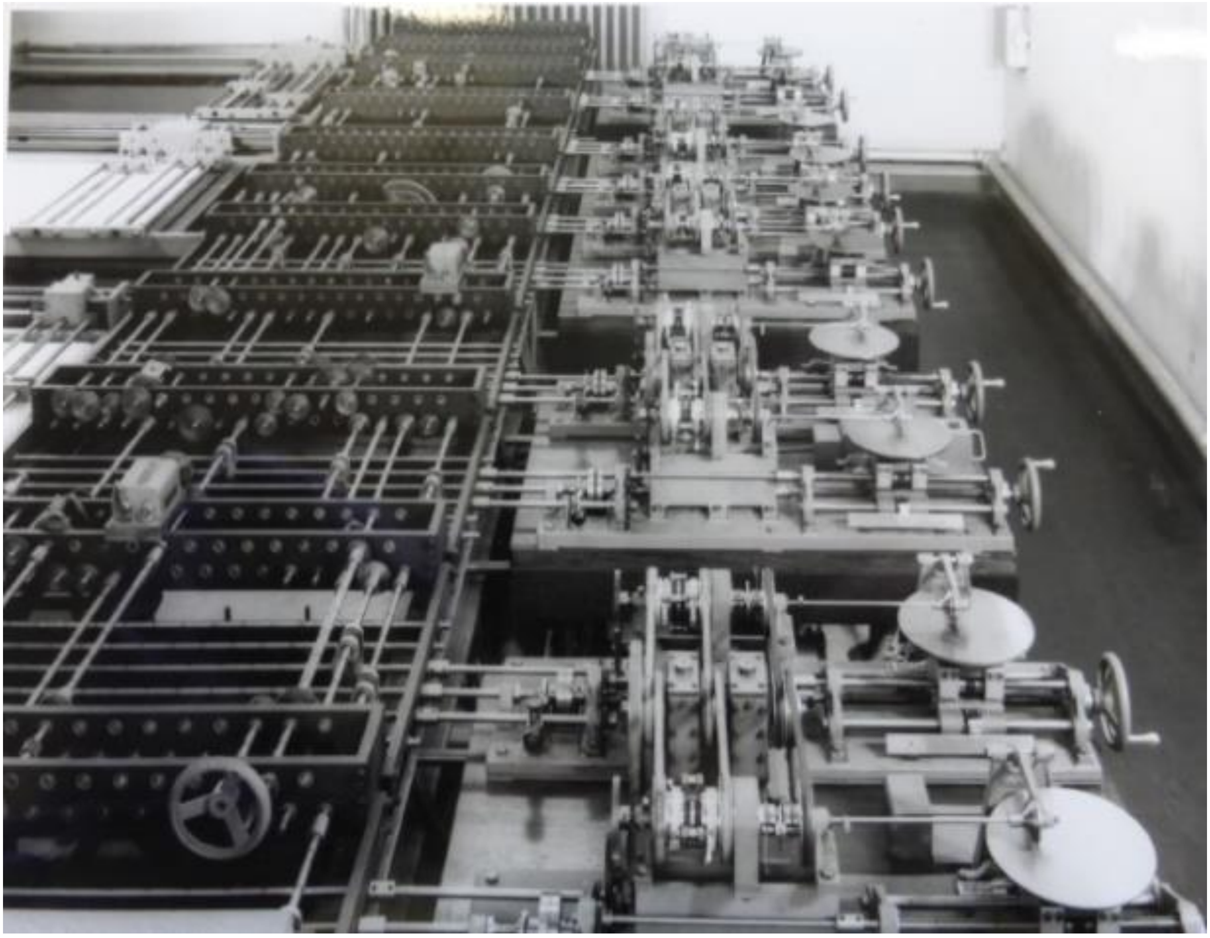

Figure 3.2: The Manchester machine, c. 1937. (© Science and Industry Museum, MSO237/25).

The Manchester machine was constructed in 1935 by Metropolitan Vickers, with four, and later eight integrating units, which allowed it to resolve higher-order equations at a faster rate than the Meccano model (see figure 3.2). The analyser was built from bespoke materials that offered a much higher level of precision than Meccano. Sir Robert McDougall (Treasurer at the University of Manchester) was instrumental in helping Hartree to secure funding for this machine from the University.[250] It had a greater level of mechanical accuracy than the original differential analyser's 98%, with a published accuracy rate of 99%.[251] A difference of

[250] D. R. Hartree, 'The Mechanical Integration of Differential Equations,' *The Mathematical Gazette*, Vol. 22 (251), (October, 1938), p. 343; and D. R. Hartree, 'News and Views; Differential Analyser for the University of Manchester,' *Nature*, Vol. 136, (April 1935), p. 940.

[251] Science Museum Archives, Wroughton, MS474/2, 'Metropolitan Vickers Log Book 1936.'

1% may not seem significant, but it dramatically increased the type and complexity of applications and equations the analyser could be used to resolve accurately. Hartree, along with Arthur Fleming (Director of Research at Metropolitan Vickers) and James Starling (Senior Mechanical Engineer at Metropolitan Vickers) worked to develop and construct the Manchester machine.[252] The new machine was delivered to the basement of the Physics Department in March 1935, where it was the most powerful calculating machine in the UK and Europe.[253] Hartree later asserted that these academics were so impressed that in the years after it was first built, the Manchester machine received a variety of broad requests for industrial applications. Hartree listed a series of these requests in a 1935 *Nature* article, including:

- Atomic structure and properties
- Performance of automatic control mechanism
- Propagation of radio waves in the Heaviside layer, regarded as a stratified medium
- Paths of electrified particles in the field of a magnet (for example, in connexion with the theory of the aurora and of cosmic radiation)
- Equilibrium and stability of stellar structures
- Vibrations of systems with non-linear restoring forces
- Transients in electrical circuits containing elements with non-linear characteristics.[254]

The variety of these requests demonstrate that the differential analyser was understood as a significant calculating machine. The majority were subsequently fulfilled by the Manchester

[252] Science and Industry Museum Archives, MSO237/21, Letter from Metropolitan Vickers to University of Manchester, 1935.
[253] M. Croarken, *Early Scientific Computing in Britain* (Oxford Science Publications, 1990), p. 51.
[254] D. R. Hartree, 'The Differential Analyser,' *Nature*, Vol. 136, (1935), p. 942.

machine before the war, with the results published in a series of papers by Hartree and his colleagues.[255]

An example of one of the applications that the Manchester machine was used for relates to electrical engineering, which required the units of the machine to be calibrated to help detect the presence of different sub-harmonics in the vibrations of systems with non-linear restoring forces. In this example, if no sub-harmonic was present, the output curve produced was a single closed loop, whereas if a sub-harmonic was present (for instance, at half the frequency of the forced oscillation), the resulting curve of *X* against *sin pt.* was a double loop (see figure 3.3).[256]

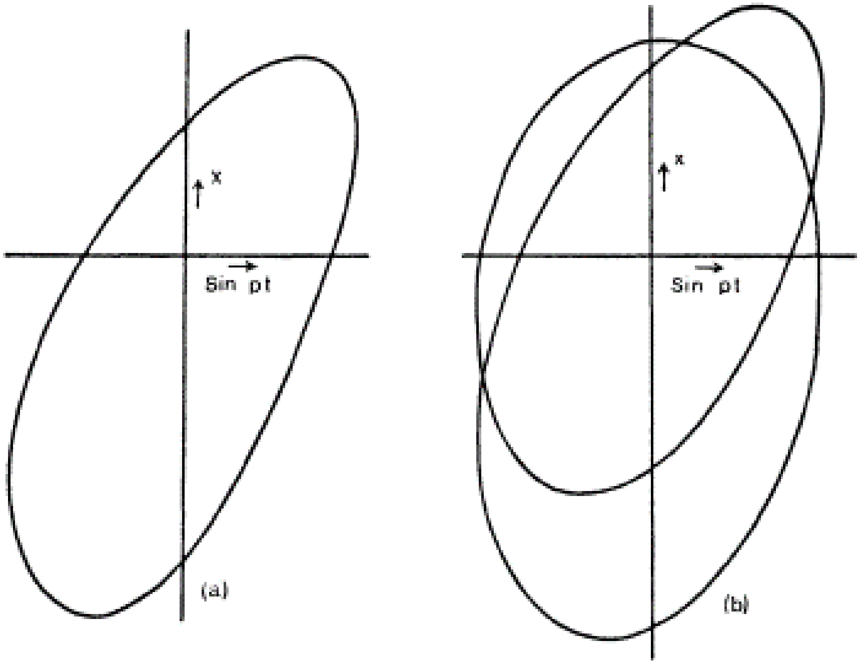

Figure 3.3: An image of the output curve solution showing the occurrence of subharmonics in a forced oscillation of a system with non-linear restoring force. (Image reproduced from D. R. Hartree, 'The Mechanical Integration of Differential Equations,' The Mathematical Gazette, Vol. 22 (251), (October, 1938)).

[255] These include: A. K. Nuttall, D. R. Hartree, and A. Porter, 'The Response of a Non-Linear Electric Circuit to an Impulse,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 32, (1936), pp. 304-320; D. R. Hartree, 'On an Equation Occurring in Falkner and Skan's Approximate Treatment of the Equations of the Boundary Layer,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 33, (1937), pp. 223-239; D. R. Hartree, B. Swirles, 'The Effect of Configuration Interaction on the Low Terms of the Spectra of Oxygen,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 33, (1937), pp. 240-249; and J. Crank, D. R. Hartree, J. Ingham, and R. W. Sloane, 'Distribution of Potential in Cylindrical Thermionic Valves,' *Proceedings of the Physical Society*, Vol. 51, (1939), pp. 952-971.

[256] A. K. Nuttall, and D. R. Hartree, 'The Differential Analyser and its Applications in Electrical Engineering,' *Journal of the Institution of Electrical Engineers,* Vol. 83 (503), (November, 1938), pp. 643-647.

Another application of the Manchester machine was concerned with the electrical surges on a finite transmission line (see figure 3.4). The analyser was used to measure the presence of these electrical surges in a lightning arrester. The output curves produced for this equation demonstrated the time variation of the potential surge across element A.[257]

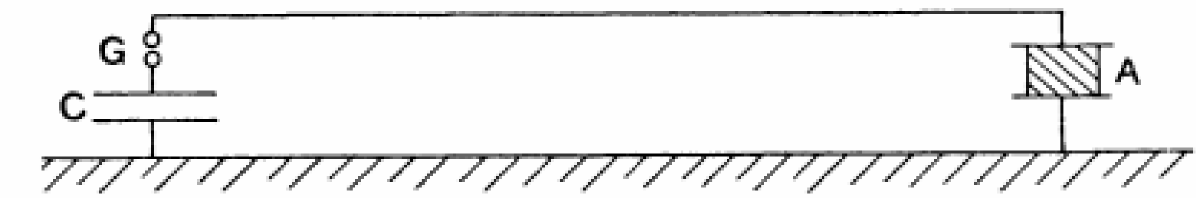

Figure 3.4: An image of the condenser, which is discharged through the breakdown of a spark gap (G), with the other end of the line being fitted with a resistive element (A). The potential difference (V) depends on the current travelling along this line (i). (Image reproduced from D. R. Hartree, 'The Mechanical Integration of Differential Equations,' The Mathematical Gazette, Vol. 22 (251), (October, 1938)).

This electrical disturbance was expressed as an output curve that was the sum of two waves travelling in opposite directions along this line (see figure 3.5).

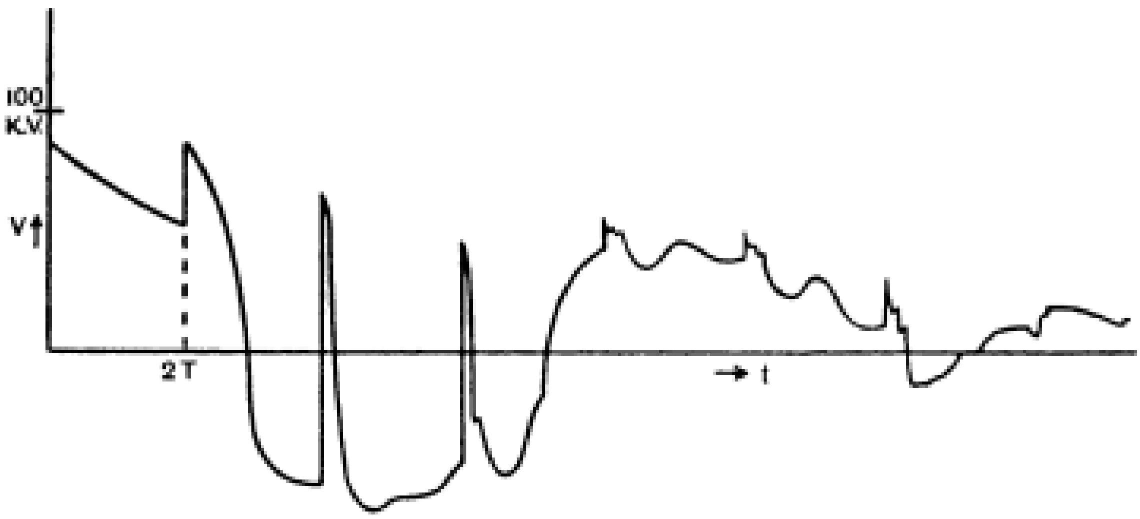

Figure 3.5: An image of an output curve giving time variation of voltage across the lightning arrester (A). (Image reproduced from D. R. Hartree, 'The Mechanical Integration of Differential Equations,' The Mathematical Gazette, Vol. 22 (251), (October, 1938)).

It was during this period that Porter left Manchester to pursue his post-doctoral studies as part of Bush's team at MIT in 1937.[258] In Porter's absence, Hartree took over the

[257] D. R. Hartree and A. Porter, 'The Application of the Differential Analyser to Transients on a Distortionless Transmission Line,' *Institute of Electrical Engineering Journal*, Vol. 83, (1938), pp. 648-656.
[258] A. Porter, 'Building the Manchester Differential Analysers: A Personal Reflection,' *Annals of the History of Computing*, Vol. 25 (2), (2003), pp. 86-92.

operation of the Manchester machine, leading a team of researchers and graduate students into the first year of the war. This initial group worked primarily on trajectory and ballistics calculations, before Hartree was seconded to the Projectile Development Establishment in Kent, as part of the Ministry of Supply in 1940.[259] Prior to this secondment, Colonel A. Phillips (Superintendent of External Ballistics at the Armament Research Department) was one of the first to use the machine for wartime applications, though he initially found that the machine was not accurate enough in peacetime. Despite Phillip's initial reservations about the accuracy rate of the Manchester machine, he realised after the onset of war that it still contained an immense value during the war for the successful calculation of these types of ballistics equations and calculate plane trajectories in standard conditions. This value was as a modelling tool, rather than strict research device, which helped to test different scenarios.

An example of this application is linked to the use of calculated trajectories to programme an automatic curve follower (a mechanism used to govern the movements of either a gun, a searchlight, or an aerial array) to make it follow the motion of a target plane. Hartree wrote after the war that the complexity of the radio pulses (each pulse was less than a microsecond) that provided this information for the automatic curve follower meant they had to be sent through 'smoothing circuits,' to avoid 'high-speed fading' of the signals collected from the target plane.[260] The challenge of high-speed fading is that the partition in an alternating current causes ripples in these signals, which it was believed could be rectified by converting the output pulses to direct current. He described how he led his team to reconfigure the units of the Manchester machine to model this process, establishing that

[259] C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific Publishing, 2003), p. 124.
[260] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

smoothing these pulses of information compromised the overall performance of the automatic curve following device (as the use of direct current would still contain ripples, requiring the use of capacitors to smooth the current and make it more even and stable).[261] Instead of smoothing circuits, this modelling work led to the development of a predictor system that resolved the issue of 'high-speed fading' and significantly increased the accuracy of fire control.[262] Hartree later asserted that using the machine to model these problems helped to highlight the challenges of accurate anti-aircraft fire control and prevented large amounts of work being wasted trying to incorporate smoothing circuits into the system. This is an example of the usefulness of analogue methods during the Second World War that does not tend to feature in histories of computing.

After Hartree's move to the Ministry of Supply in 1940, the responsibility for the operation of the Manchester machine passed to two of his graduate students John Ingham and Malcolm Nicholson. They managed the continued use of the Manchester machine to resolve other ballistics equations until late 1940 when Nicholson was called up for the war effort. Following Nicholson's departure, Nicholas Eyres and Phyllis Nicholson joined with Ingham to manage the work of the machine, which had by this time come to be understood more as a useful modelling tool that could quickly produce indicative results and save staff-hours.[263] This usefulness increased the variety of equations and problems that the team received before Hartree's promotion to the Headquarters staff of the Department of Scientific Research in 1941. This promotion meant that he could once again assist with the work of the

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[261] P. T. Krein, and D. C. Hamill, 'Smoothing Circuits,' *Wiley Encyclopaedia of Electrical and Electronics Engineering* (1999), https://doi.org/10.1002/047134608X.W2286 [accessed 21 June 2017].
[262] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).
[263] C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific Publishing, 2003), p. 124.

Manchester machine team, who had been tasked with resolving calculations that helped to model the variable heat flow in the processes concerned with the manufacture of steel. Ingham left the team in late 1941, leading Hartree to ask his former student Jack Howlett to join in his place. The analyser team was strengthened further in 1942 with the addition of Jack Michel, who along with Howlett, Eyres, and Nicholson remained until the end of the war (see figure 3.6).

Figure 3.6: An image of the 'job shop' team working on the Manchester machine during the period from 1941-1943. Left to right, front to back, includes Jack Howlett, Nicholas Eyres, Jack Michel, Douglas Hartree, and Phyllis Nicholson. (Image reproduced from http://www.computerconservationsociety.org/resurrection/res52.htm).

Hartree emphasised the importance of his team after the war, stating 'A group of four is necessary in order to have enough manpower to use the machine effectively on many problems to which it may be applied, though some of the simpler problems can be handled by a smaller number.'[264] Howlett later referred to this group as Hartree's differential analyser 'job shop,' explaining how each member was proficient in calibrating and using the different units of the machine to resolve specialised problems, and that each supervised teams from different areas of industry when they came to use the machine.[265]

Alongside leading the work of his 'job shop,' Hartree was also responsible for the work of the Magnetron Research Group at the Ministry of Supply. He described the 'job shop's' crucial role in using the Manchester machine to develop the electronics of the radar magnetron valve, a device that creates short-spectrum, low-frequency electromagnetic radio waves.[266] The magnetron produced these waves, sending them into the sky through an antenna, where enemy planes would reflect them back at the antenna, causing a blip to appear on the screen. These waves are more commonly understood today as microwaves (the same ones used to cook food). The Manchester machine contributed to the invention of a radar magnetron that was small enough to be used in planes and ships in 1939, which opened up an entirely new field of work, relating to how magnetrons could be improved to increase the accuracy of radar.[267] Nicholson was tasked to use the machine to develop the radar magnetron electronics and radio propagation throughout the war, working with David Copely and Oscar Buneman.[268] They primarily used the analyser to calculate the orbits of

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[264] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).
[265] J. Howlett letter to Jim Hailstone, 11 November 1995, Atlas Computer Laboratory, www.chilton-computing.org.uk/acl/literature/earlyhistory/p018.htm [accessed 13 March 2018]; and D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).
[266] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946); and L. A. Manning, 'Radio Propagation Following World War Two,' *Proceedings of the Institute of Radio Engineering*, Vol. 50, (1962), pp. 709-711.
[267] For more on the topic of oscillating magnetrons and microwaves, refer to J. Benford, J. A. Swegle, and E. Schamiloglu, *High Power Microwaves* (Taylor Francis, 2007).
[268] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

electrons in an oscillating magnetron, which they used to help increase its efficiency (see figure 3.7).

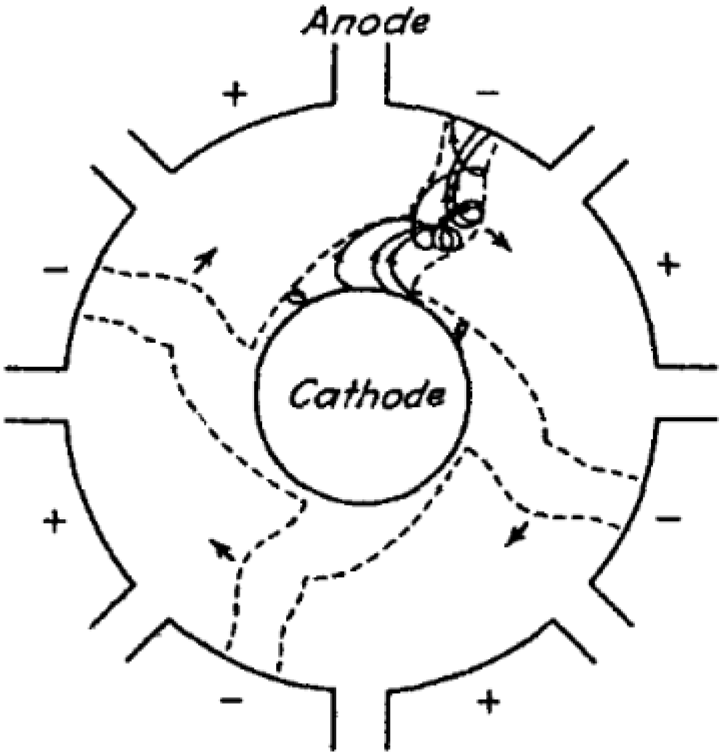

Figure 3.7: An image of the orbits of electrons in an oscillating magnetron; the solid lines highlight the paths of electrons during the process of rotation. (Image reproduced from Reich. H. et al., *Microwave Theory and Techniques* (New York, 1953), reproduced in C. F. Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific Publishing, 2003).

Their work with the Manchester machine assisted in the discovery of the Buneman-Hartree criterion. This criterion indicated a voltage threshold at which a magnetron would most effectively operate, and the voltage level below which, it was impossible to maintain oscillations (see figure 3.8). Hartree and the 'job shop' continued to investigate different aspects of the operation of the magnetron throughout the war, until the increasing complexity of magnetron oscillations made it impossible to reduce the equation to the numerical values to allow it to be resolved the Manchester machine. While this increased complexity resulted in these equations being transferred to other analogue and digital machines, this should not detract from the role of the Manchester machine in helping to develop this technology.[269]

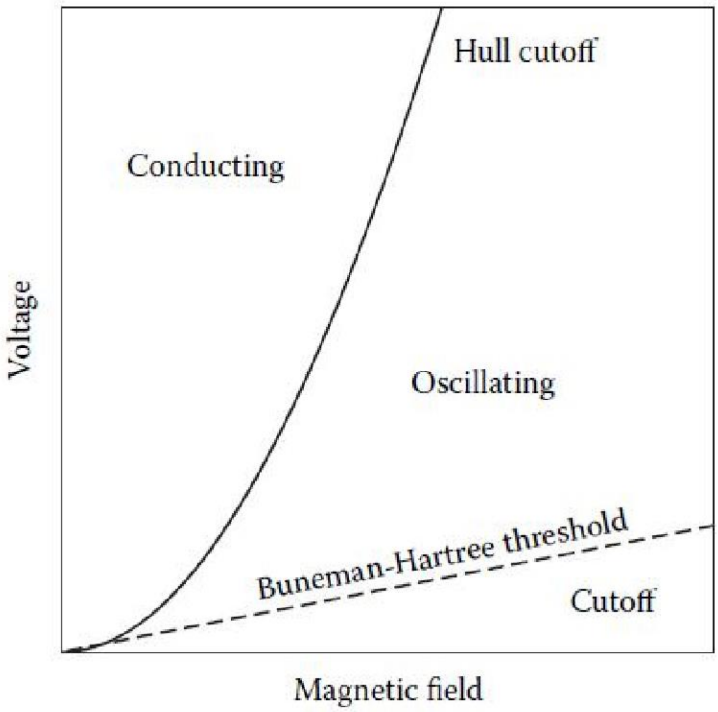

Figure 3.8: An image demonstrating the Buneman-Hartree threshold and the operating domains of an oscillating magnetron. (Image reproduced from J. Benford, J. A. Swegle, and E. Schamiloglu, *High Power Microwaves* (Taylor Francis, 2007)).

The continued usefulness of the machine in modelling equations and producing indicative results led to it being used by a variety of government departments as the war progressed. In 1942, the Aerodynamics Section of the Royal Aircraft Establishment at Farnborough submitted a problem to the 'job shop' team, relating to the control of an aircraft's motion after the failure of one of its components. The Manchester machine was used to model this problem until 1944, producing solutions to over 1,500 different scenarios based around various combinations of variables, including wind, air-speed, gravity, and velocity.

[269] J. Howlett interview transcript, including reflections on a paper by M. Croarken, conducted at Chilton Computing, 29 April, 1993, www.chilton-computing.org.uk/acl/associates/permanent/howlett/croaken.htm [accessed 20 March 2018].

During this same period, Howlett was tasked to work on a problem requested by the Admiralty Mine Design Department in 1942. It involved investigating and developing a model to understand the motion and propagation of a non-spherical bubble arising as a result of an underwater explosion caused by a mine.[270] Eyres's primary area of work throughout the war was on variable heat flow, which involved using the machine to calculate the asymmetrical heat flow in different cylinders; a request that came from researchers at Hadfields, Ltd., of Sheffield, (with whom Eyres would later publish after the war). Together they reconfigured the analyser to allow it to resolve these partial-differential equations, a technique which Hartree believed dramatically increased the scope of equations that these analogue machines could be used to calculate.[271] These examples demonstrate how the Manchester machine was continually developed and used in parallel to digital methods to help resolve different wartime problems as they arose.

However, perhaps the most prominent contribution that the Manchester machine made to the British war effort arguably occurred in 1943. Hartree and the other members of the 'job shop' were approached by an unnamed physicist (later revealed to be Rudolf Peierls, who was working with Otto Frisch at the University of Birmingham) to help resolve a calculation.[272] Howlett explained that in contrast to previous requests that had clear, real-world applications from the outset, the group was not given any indication as to the origin of the problem except that it was '...a non-linear parabolic partial-differential equation.'[273]

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[270] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

[271] N. R. Eyres, D. R. Hartree, J. Ingham, R. J. Sarjant, and J. B. Wagstaff, 'The Calculation of Variable Heat Flow in Solids,' *Philosophical Transactions of the Royal Society*, Vol 240, (1946), pp. 1-57; and D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

[272] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

[273] J. Howlett letter to Jim Hailstone, 11 November 1995, Atlas Computer Laboratory, www.chilton-computing.org.uk/acl/literature/earlyhistory/p018.htm [accessed 13 March 2018].

Nevertheless, the group used the Manchester machine to find the solution within less than a year, with Howlett admitting that the team speculated as to the origin of the unknown physical problem that they were resolving. He later explained that Hartree had correctly guessed that the equation related to the separation of uranium 235 isotopes and uranium 238 isotopes by process of diffusion, and that the equation they had worked on was part of the Tube Alloys programme (that contributed to the Manhattan Project).[274] The output curve for this equation represented the time needed to produce the required amount of uranium 235 isotopes. Peierls used this information to help develop an accurate estimation of the amount of the isotope necessary to create and sustain a chain reaction explosion in an atomic bomb.[275]

Towards the end of the war, Nicholson led the group's work in resolving the problems of radio propagation, basing her work on Hartree's publications from 1923 to 1931 on the Appleton-Hartree equation.[276] Her approach undertook a ray treatment that was similar to Hartree's prior work on wave propagation in a stratified medium.[277] She used the Manchester machine to test the relationship between the propagation of radio waves and meteorological conditions. Her work on radio propagation would later feed into the development of GEE, a hyperbolic navigation system that measured the time delay between different radio signals

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[274] For more on the Tube Alloys project in relation to the Manhattan project, refer to M. Gowing, *Britain and Atomic Energy 1939–1945* (Macmillan, 1964).
[275] J. Howlett interview transcript, including reflections on a paper by Dr. M. Croarken, conducted at Chilton Computing, 29 April, 1993, www.chilton-computing.org.uk/acl/associates/permanent/howlett/croaken.htm [accessed 20 March 2018].
[276] I. Shkarofsky, 'Generalized Appleton-Hartree Equation for Any Degree of Ionization and Application to the Ionosphere,' *Proceedings of the Institute of Radio Engineers*, Vol. 49 (12), (1961), pp. 1857-1871.
[277] D.R. Hartree, P. Nicholson, N. Eyres, J. Howlett, and T. Pearcey, 'Evaluation of the Solution of the Wave Equation for a Stratified Medium,' *Air Defence Research & Development Establishment*, No. 47, (May 1944); and Research Report No. 279, (March, 1945). Hartree later presented this work at a conference in 1946 for the Physical Society and the Royal Meteorological Society, published in 1947; D. R. Hartree, J. G. L. Michel, and P. Nicholson, Practical Methods for the Solution of the Equations of Tropospheric Refraction: Meteorological Factors in Radio-Wave Propagation,' *Report of a Conference held on April 1946 at the Royal Institute of London* (Physical Society and Royal Meteorological Society, 1948), pp. 127-168

to provide a location for an aircraft flying overhead.[278] This is more commonly understood today as radar technology.

After the war, the Manchester machine was moved to the National Physical Laboratory, where it remained until 1954. It was subsequently sent back to the Simon Engineering Laboratory at the University of Manchester where it was repaired and demonstrated by Jack Diamond. The repaired machine was used as a modelling and teaching device to assist in the development of new analogue and digital methods, before being offered to both the Science and Industry Museum in Manchester and the Science Museum in London in the 1970s.[279] Due to its large size, half of the machine was sent to the Science Museum (where it is used in the *Mathematics: The Winton* gallery), while the other half at the Science and Industry Museum in Manchester (where it is used in the 1830 Warehouse, a space dedicated to the development of modern computing) (see figure 3.9).[280]

These wartime and post-war uses of the Manchester machine help to change our understanding of the object. While the Manchester machine was initially designed as a research tool and a mathematical and scientific machine, the exhibitions of this object today do not account how its identity has changed. This exploration of the alternative applications of the Manchester machine during the Second World War provides a course for how these

[278] While the Manchester machine worked on refraction of rays in the lower atmosphere, the Cambridge Machine was used for the wave treatment of the refraction of radio waves in the upper atmosphere. For more information on the 'GEE' project, refer to L. Brown, *A Radar History of World War II: Technical and Military Imperatives* (Institute of Physics Publishing, 1999), pp. 300-431.
[279] Science and Industry Museum Archives, MSO237/26, 'Pugh letter to Professor J. Diamond at the Simon Engineering Lab, 5 November 1973.'
[280] 'Manchester University Differential Analyser,' http://collection.sciencemuseum.org.uk/objects/co8555623/manchester-university-differential-analyser-analogue-computer-differential-analyser [accessed 20 March 2016]; and 'The 1830 Warehouse,' https://www.scienceandindustrymuseum.org.uk/about-us/venue-hire/1830-packages [accessed 25 June 2018].

two museums can reduce the prevalence of the ‘analogue gap’ between analogue and digital methods that continues to exist in their exhibits.

Figure 3.9: An image of half of the Manchester machine in situ at the Science and Industry Museum in Manchester (SIM). (© Science & Society Picture Library Prints).

2.2. Cambridge Meccano model

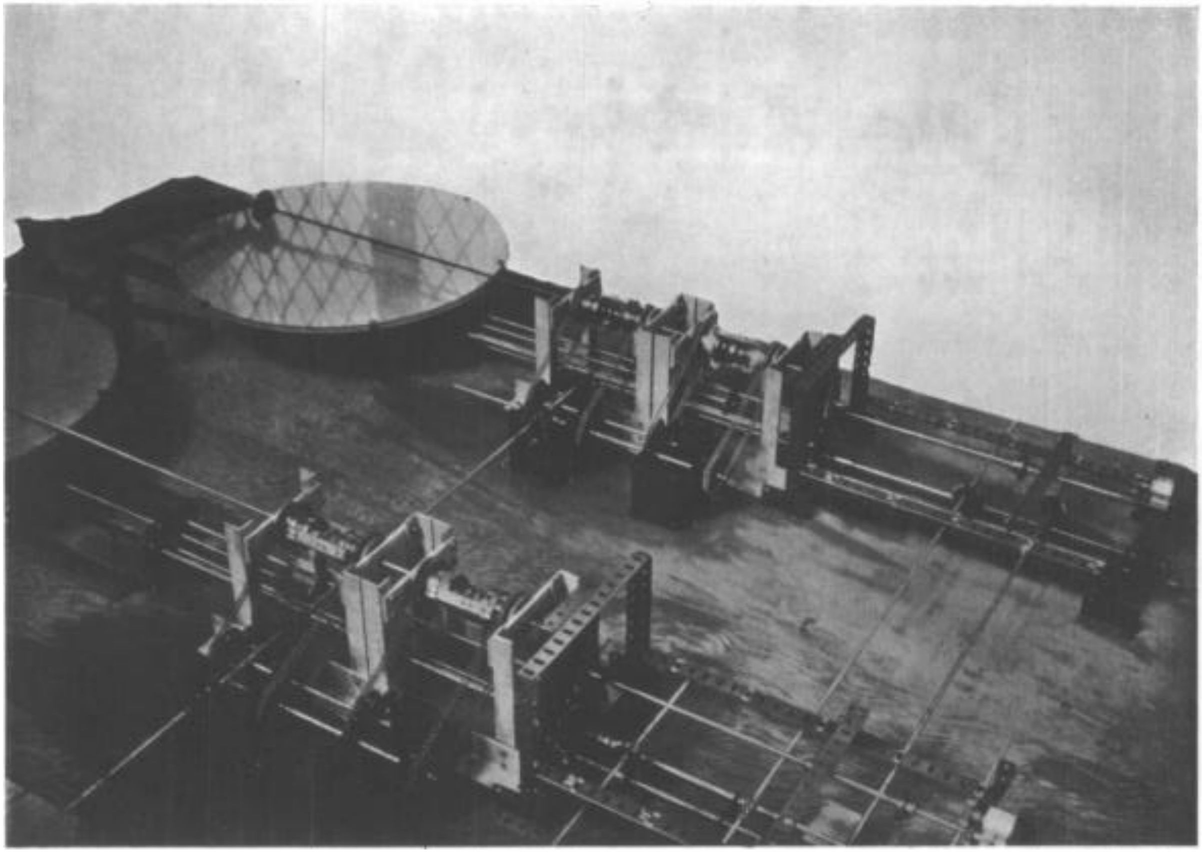

Figure 3.10: An image of the Cambridge Meccano model differential analyser, c. 1939. (Image reproduced from J. E. Lennard-Jones, M. V. Wilkes, and J. B. Bratt, 'The design of a small differential analyser,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 35 (3), (July, 1939), plate I).

John Lennard-Jones, Maurice Wilkes, and J. B. Bratt built the second differential analyser in Britain at the University of Cambridge in 1935. The analyser was also built from Meccano and had five integrating units (see figure 3.10). It borrowed from Hartree and Porter's initial designs and featured many upgrades, including lashlocks, hardened steel integrating wheels, improved torque amplifiers, and larger integrating discs. The upgrades meant that when calibrated for the circle test, the accuracy rate was above 98%, surpassing Hartree and Porter's Meccano analyser. Lennard-Jones, Wilkes, and Bratt later summed the Cambridge Meccano model up before the war, stating that 'While not claiming that such a high degree of accuracy can always be guaranteed, we consider that these examples show that the Cambridge Meccano model is not simply a toy, but is capable of serious work.'[281] The success of these improvements led to their incorporation in the subsequent plans for the Manchester and Cambridge machines.

The Cambridge Meccano model was used for a variety of applications before the war, including Wilkes' work on ionospheric radio propagation.[282] As a research student at the Cavendish Laboratory, Wilkes developed a technique for calculating this radio propagation, which later became a recognised and widely used mode of signal transmission for communication during the Second World War.[283] Lennard-Jones submitted a report to the Faculty Board of Mathematics at Cambridge based on these initial successes of the Cambridge Meccano model, requesting the development of a larger bespoke differential analyser similar to the Manchester machine (which became the Cambridge machine).[284] His request was part of a larger paper that called for the establishment of a Computer Laboratory at Cambridge to be based around mechanical analysers and other counting machines.[285]

The Faculty of Mathematics commissioned a report in response to this paper that supported Lennard-Jones' request for a larger differential analyser, awarding him £5,000 to build an eight-integrator machine with Metropolitan Vickers. The board commented that the

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[281] J. E. Lennard-Jones, M. V. Wilkes, and J. B. Bratt, 'The Design of a Small Differential Analyser,' *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 35 (3), (July, 1939), p. 493.
[282] J. E. Best, J. A. Ratcliffe, and M. V. Wilkes, 'Experimental Investigation of Very Long Wireless Waves Reflected from the Ionosphere,' *Proceedings of the Royal Society A*, Vol. 156, (1936), pp. 614-633; and K. G. Budden, J. A. Ratcliffe, and M. V. Wilkes, 'Further Investigations of Very Long Wireless Waves Reflected from the Ionosphere,' *Proceedings of the Royal Society A*, Vol. 171, (1939), pp. 188-214.
[283] M. V. Wilkes, 'Theory of Reflection of Very Long Wireless Waves from the Ionosphere,' *Proceedings of the Royal Society A*, Vol. 175, (1940), p. 143.
[284] Churchill College Archives, LEJO Folder 5, J. E. Lennard-Jones, 'Submission to Faculty of Mathematics,' (1935), p. 21.
[285] Three types of machines were mentioned: mechanical Brunsviga machines of German origin, which were operated by cranking a handle, and Monroe and National machines, which were electrically operated. For more information, refer to H. Ahmed, *Cambridge Computing: The First 75 Years* (University of Cambridge Press, 2014), p. 23.

‘working model ... constructed in this university … proved to the satisfaction of the board that the claims made for the larger machines are justified’ (see figure 3.11).[286]

Figure 3.11: An image of the Cambridge team operating the Cambridge Meccano Model Differential Analyser in the Theoretical Chemistry Laboratory in 1937. (Left to right), A. F. Devonshire, J. Corner, and M. V. Wilkes. (© Science & Society Picture Library Prints).

The report also led to the creation of the Mathematical Laboratory in 1937 that provided computing facilities for the various departments of the University. Wilkes was an assistant at the newly formed laboratory, where his role was as an operator of the Cambridge Meccano model analyser on behalf of staff from other departments. However, the onset of war led the Mathematical Laboratory, the Cambridge Meccano model, and the imminent Cambridge machine to be taken over by the Ministry of Supply, which changed the way the analysers were used.

[286] Churchill College Archives, LEJO Folder 6, ‘Cambridge Faculty Report,’ (1936), pp. 1-2.

The primary application of the Cambridge Meccano model during the war was at the Department of Exterior Ballistics, where it was intended to be used to resolve shell trajectory calculations.[287] However, as the ballistics calculations increased in complexity, the Cambridge Meccano model was no longer accurate enough for this initial application. Instead, it was used for other wartime armaments requirements, including modelling thermal conduction and convection problems, detonation waves of high explosives, and electrical transmission line studies.[288]

After the war, the Cambridge Meccano model was purchased by a former Ph.D. student, and analyser operator, Harry Whale. He transported it to the University in Auckland in 1948, where it continued to be used as a research tool at the Seagrove Radio Research Station before being transported to the Australian Department of Scientific and Industrial Research (DSIR) in 1950.[289] At the DSIR, the Cambridge Meccano model was calibrated to resolve equations linked to energy systems including, geothermal studies, Waikato river hydro-electric studies, and rabbit population predictions. However, as the order and complexity of these equations extended past the boundaries of the Cambridge Meccano model, its use for research purposes decreased. Instead, the performative nature of the analyser's glass wheel-and-disc integrators meant that it was increasingly used as a teaching aid at Wellington Polytechnic University throughout the 1960s and early 1970s.[290] The model was subsequently donated to the Museum of Transport and Technology Auckland (MOTAT)

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[287] J. Dalton, 'Continuing the Saga of the Differential Analyser,' *Meccanoman's Newsmag*, No. 68, (March, 1994), p. 4.

[288] H. Ahmed, *Cambridge Computing: The First 75 Years* (University of Cambridge Press, 2014), p. 29; and W. Irwin, 'The Cambridge Meccano Differential Analyser No. 2' *Computer Conservation Society*, (2013), http://www.cs.man.ac.uk/CCS/res/res64.htm#f [accessed 31 October 2016].

[289] T. Robinson, 'The Meccano Set Computers: A History of Differential Analysers made from Children's Toys,' *IEEE Control Systems Magazine*, Vol. 25 (3), (June, 2005), pp. 16-35.

[290] W. Irwin, 'The Differential Analyser Explained,' *Auckland Meccano Guild* (2009), http://amg.nzfmm.co.nz/differential_analyser_explained.html [accessed 31 October 2016].

in 1973, where Whale – reunited with the analyser twenty-five years after he had first brought it to New Zealand – refurbished the integrators. After this repair work, the analyser was put on public display as an example of an early analogue computer (see figure 3.12).

Figure 3.12: An image of the Cambridge Meccano model Differential Analyser in situ at the MOTAT museum, c. 2010. (Image reproduced from Auckland Meccano Guild website, http://amg.nzfmm.co.nz/differential_analyser.html).

However, the Cambridge Meccano model was taken off display in the subsequent years and placed in the museum's store, where it was unintentionally damaged and presumed lost. It was rediscovered in 1993, leading to a series of articles being published in the *New Zealand Herald* and the *New Scientist*. These articles maligned MOTAT's failure to preserve the Cambridge Meccano model and called for a concerted effort to restore what did remain into a permanent display of it in 'working condition.'[291] The Cambridge Meccano model was subsequently repaired and currently sits in MOTAT as the only other example of an original Meccano differential analyser, as a counterpart to the Trainbox. Among the machines

[291] D. King, 'Historic Computer Lost from MOTAT,' *New Zealand Herald*, (April 20, 1993), p. 5; D. King, 'Heritage Rusts to Bits in Rain,' *New Zealand Herald*, (April 27, 1993), p. 5; and I. Lowe, 'Ancient Computer Down and Out,' *New Scientist*, Vol. 138 (1873), (15 May, 1993), p. 50.

discussed in this chapter, the Cambridge Meccano model is closest in physical form and function to the original differential analyser. While the public history of the Cambridge is the same as the Trainbox – as a Meccano machine that was later used as a teaching device after having been 'replaced by faster digital computers' – the alternative display of the Cambridge Meccano model means that it sits as an interesting counterpoint to the Trainbox on display at the Science Museum.[292] The various applications of this machine provide further examples of how analogue differential analysers were continually developed in parallel to digital computers during this period; first for research, then modelling applications, and finally to teach calculus and the mechanical processes of integration.

[292] MOTAT Differential Analyser [Meccano], https://collection.motat.org.nz/objects/47995 [accessed 20 July 2018].

2.3. Cambridge machine

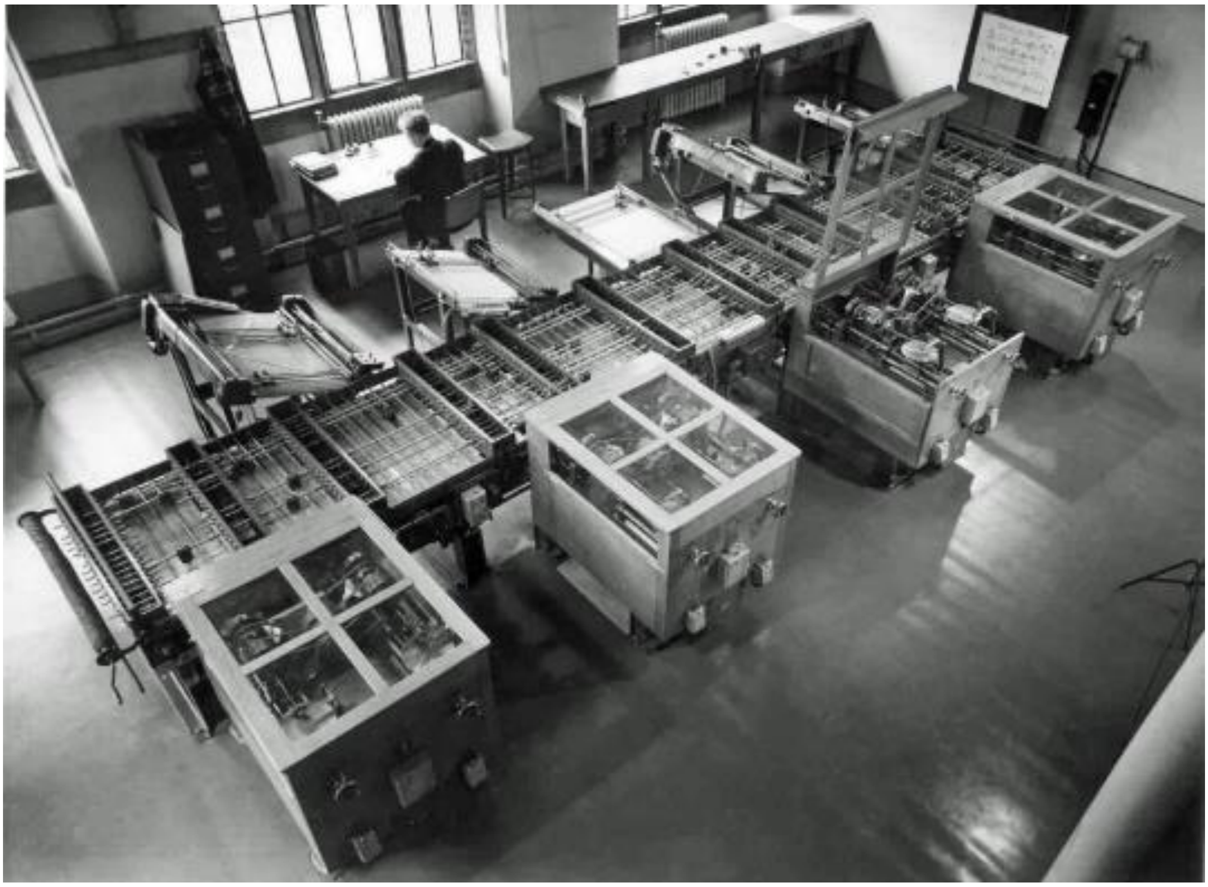

Figure 3.13: An image of the Cambridge machine in the Cambridge Mathematical Laboratory, c. 1939. (© University of Cambridge Archive Photos, Creative Commons).

Metropolitan Vickers delivered the Cambridge machine in October 1939, whereupon the Board of Ordnance immediately requisitioned it for wartime applications (see figure 3.13).[293] Lennard-Jones created a research team to work on the Cambridge machine and model at the University's Mathematical Laboratory, similar to Hartree's 'job shop' at Manchester. Like Hartree, he supported the group's work throughout the war, alongside serving as Chief Superintendent of Armament Research, and later as Director General of Scientific Research at the Ministry of Supply. His team included J. Wilkinson, H. Whale, G. Wood, T. Vickers, E. Goodwin, and A. Devonshire, who initially worked in shifts to keep the differential analyser resolving equations for twelve hours at a time. During the early years of

[293] H. Ahmed, *Cambridge Computing: The First 75 Years* (University of Cambridge Press, 2014), p. 29.

the war, the work of the group was focused on the trajectory calculations of ballistics.[294] However, as with the other analysers in this section, the Cambridge machine could not resolve the high-precision trajectory calculations that were required, despite having the highest accuracy rate of any British analysers when it was completed.[295] As with the other machines from this period, this resulted in the Cambridge machine being used for other research and experimental applications that did not require high levels of precision and accuracy.

The machine was used to model solutions to equations for the conduction and convection in heat transfer, electrical transmission lines, sound ranging, and the propagation of detonation waves of high explosives.[296] There is also a commonly-held belief that the Cambridge team had used the machine to assist in Barnes Wallis' work on the development of the 'bouncing-bomb.'[297] This evidence for this application hinges on the fact that the scaled-drag coefficients of Wallis' bouncing bombs can be reduced to a similar set of nonlinear second-order ordinary differential equations, meaning that it was technically possible for the Cambridge machine to have been used for these applications. The main link is the scaled-drag coefficients of the 'Magnus effect.' A simple way to understand the Magnus effect is to visualise how a football moves when it is kicked with the instep.[298] The forces applied to the football include velocity, drag, rotation, and the axis of rotation, weight, and lift-side force, which, written as a second-order equation is as follows:

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[294] UK National Archives, DEFE 15/751-C20779, Memorandum No. 27/44, W. J. Cairns, J. Crank, and E. C. Lloyd, 'Some Improvements in the Construction of a Small-scale Differential Analyser and a Review of Recent Applications,' *Armament Research Department Theoretical Research*, (1944).

[295] While it had the highest accuracy rate, it was not the most powerful analyser at the onset of war. The most powerful analyser in Britain at this point was the Manchester machine, which had a higher number of integrators than the Cambridge machine when it was first delivered.

[296] T. Robinson, 'The Meccano Set Computers: A History of Differential Analysers made from Children's Toys,' *IEEE Control Systems Magazine*, Vol. 25 (3), (June 2005) p. 21.

[297] The earliest reference to this application featured in Anon., 'Toy Used to Build 'Brain Box' in 1930s,' *New Zealand Herald*, (2 June 1973).

[298] This example is taken from M. Ahmad, 'Bend it like Magnus: Simulating Soccer Physics' *Physics Department, The College of Wooster Ohio*, (14 May, 2011), pp. 1-8.

$$F = m\frac{dv}{dt} = m\,\frac{d^2s}{dt^2} = ms''(t)$$

Put simply, this equation describes how, if a ball is hit with enough spin, it begins to move, or bend away from the expected trajectory. The three forces that act on the ball in this example equation are gravity, a proportional drag force to the velocity of the ball, and the Magnus effect force, which is applied in a direction perpendicular to the angular velocity of the ball.[299] Wallis' work on the bouncing bomb employed the same set of concepts, leading to the decision to rotate the bombs backwards (utilising the Magnus effect), which proportionally increased the object's aerodynamic lift (via the Kutta–Joukowski Theorem).[300] However, while the parabolic curves of the bouncing bombs – part of Operation Chastise – lend themselves to numerical equations that could be programmed into the Cambridge machine, there are no official papers that substantiate this claim.[301]

Nevertheless, Wilkes explained that he believed the machine had been used for the calculations relating to the bouncing bombs project, while Porter made similar comments in a 2007 discussion with Professor Bonita Lawrence from Marshall University.[302] However, neither Wilkes (who had initially managed the day-to-day running of the Cambridge Meccano model in 1936, but was called up by the Telecommunications Research Establishment (TRE) in 1939 and did not return to Cambridge until 1945) nor Porter worked as part of Lennard-Jones' team during the war, a fact that makes it difficult to say with certainty that this was an application of the Cambridge machine.

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[299] Ibid. p. 2.
[300] For more on the Kutta-Joukowski Lift Theorem, refer to G. K. Batchelor, *An Introduction to Fluid Dynamics* (Cambridge University Press, 1967).
[301] For more on 'Operation Chastise,' refer to D. C. Dildy, *Dambusters: Operation Chastise* (Osprey Publishing, 2010).
[302] M. V. Wilkes, *Memoirs of Computer Pioneer: Maurice Wilkes* (MIT Press, 1986); and Bonita Lawrence, personal communication, 10 April 2018.

In comparison to the Manchester machine that is used to tell mathematical and technological stories at the Science Museum and SIM, and the Cambridge Meccano model, which is used as a teaching tool at MOTAT, the Cambridge machine is displayed primarily as a computing object. The differences between these identities of the three analysers today confirm the continuation of the 'analogue gap' in museums, and the need for both historians and curatorial staff to reconsider the stories they are used to tell alongside digital machines.

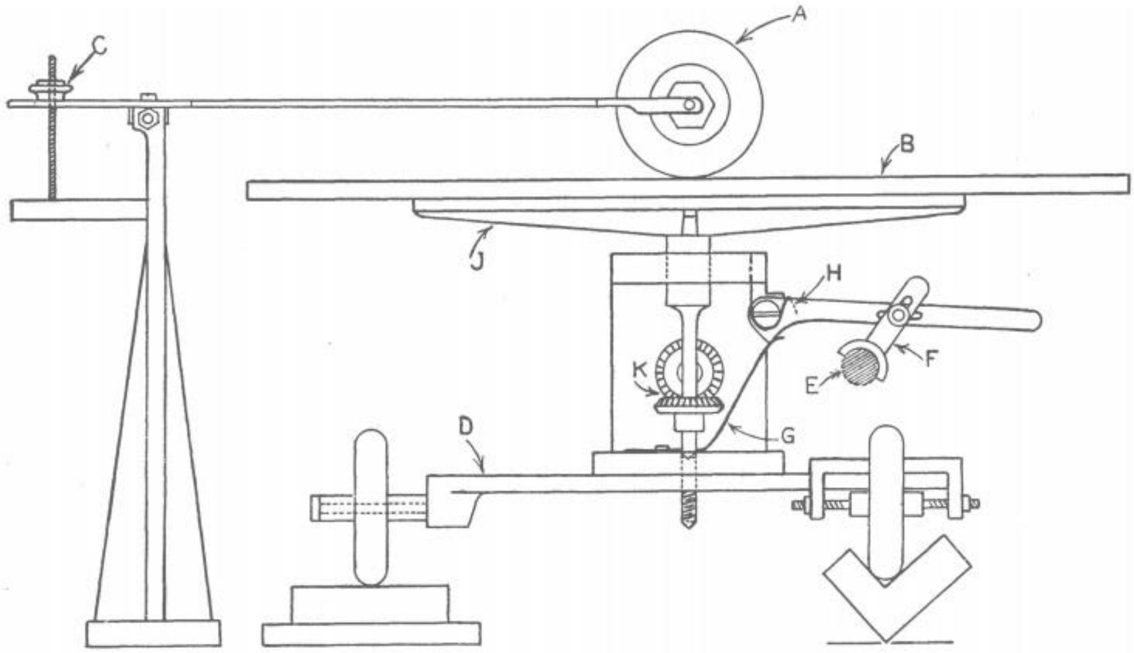
3. Secondary Differential Analysers

This section tells the stories of the 'secondary' differential analysers that were constructed in the UK before, during, and after the Second World War, discussing the design of the machines and their applications (see figure 3.14). I have classed these analysers together as they were constructed outside of Manchester and Cambridge, by other academics, amateur enthusiasts, and those in industry. It collates their stories to provide further examples of the significant applications of this technology, which demonstrate that analogue technology was used in parallel to digital methods, and that many machines were used for teaching purposes during and after the war. They also provide further context on Hartree's decision in 1947 to rebuild the Trainbox as a teaching device.

Date	Constructor(s)	Materials	Location	No. of Integrators
1937	Massey, Wylie, Buckingham, and Sullivan	Non-Meccano	Queen's University, Belfast	4
1937	Worthy	Meccano	Pocklington School, York	2
1938	Stone	Meccano	Macclesfield Grammar School	2
1939	Beard	Non-Meccano	Pearl Assurance Company	6
1940	Womersley	Non-Meccano	Armament Research Department	Destroyed before completion
1940	Benson	Meccano	Coast Artillery Experimental Establishment, UK	Unknown
1942	Wood	Non-Meccano	University of Birmingham	2 (6)
1943	Sloane	Meccano	Air Defence Research and Development Establishment	Unknown
1945	Eyres	Meccano	Radley College, Oxfordshire	2

Figure 3.14: A table of the differential analysers constructed outside of the University of Manchester and Cambridge before and during the Second World War. (Data collated by author).

Massey constructed a four-integrator non-Meccano model differential analyser with assistance from J. Wylie at Queen's University, Belfast in 1938. Unlike their peers at Manchester and Cambridge, they did not use Meccano to construct for the analyser, instead opting to use parts from the University's Machine Workshop. Despite the different designs and materials of this machine compared to those at Manchester and Cambridge, it was initially used to resolve similar equations, including the wave functions of the hydrogen atom and inhomogeneous wave equations (see figure 3.15).[303] It was later used to resolve equations for the photo-ionisation cross-section of oxygen atoms in the upper atmosphere, the Self-Consistent Field Theory, and the properties of low-temperature helium atoms.[304]



A Integrator wheel.
B Glass disc.
C Screw providing independent support for integrator wheel.
D Carriage.
E Section of lead screw.
F Half-nut attachment between carriage and lead screw.
G Main spring operating half-nut attachment.
H Wire spring.
J Brass plate mounted on spindle.
K Gears connecting splined shaft with disc.

Fig. 1.
The Integrating Unit.

Figure 3.15: A schematic image of Massey's integrating unit. (Image from H. S. W. Massey, J. Wylie, R. A. Buckingham, and R. Sullivan, 'A Small-scale Differential Analyser: Its Construction and Operation,' *Proceedings of the Royal Irish Academy Section A*, Vol. 45, (1938)).

[303] H. S. W. Massey, J. Wylie, R. A. Buckingham, and R. Sullivan, 'A Small-scale Differential Analyser: Its Construction and Operation,' *Proceedings of the Royal Irish Academy*, *Section A*, Vol. 45, (1938), p. 17.
[304] H. S. W. Massey, and R. A. Buckingham, 'The Low-Temperature Properties of Gaseous Helium,' *Proceedings of the Royal Society of London A*, Vol. 168, (1938), pp. 378–389.

The successful application of the machine to these problems led Massey to describe it as 'robust and capable of giving results to an average accuracy of [98-99] per cent,' a rate similar to those at Manchester and Cambridge.[305] Massey organised the transfer of his differential analyser to University College London in 1938 after he succeeded L. Filon as the Goldsmid Professor of Mathematics. However, the analyser was destroyed in an air raid in the early days of the war. Despite resolving some significant equations, Massey did not try to rebuild it, and instead took up the position of Principal Experimental Officer at the Admiralty Research Laboratory in December 1939. In this role, he gradually moved away from using the method of differential analysis, working instead to redevelop the shape of ship hulls to counter the problems of German magnetic mines. Later in the war, Massey moved to become the Deputy Chief Scientist at the Scientific Section of Mine Design Department in Hampshire.[306] While Massey's non-Meccano analyser was initially used as a research tool, its sudden destruction makes it difficult to know how this object would have developed during the war.

William 'Digby' Worthy was a 14-year-old schoolboy when he built a two-integrator Meccano model differential analyser at Pocklington School, Yorkshire in 1938. While his analyser has long since been lost, copies of Worthy's original mathematics and physics workbooks are still held by the school today. In these books, he describes his decision to reduce the complexity of the original differential analyser by modifying the design of his analyser. He replaced the complex-gearing system that featured in Hartree and Porter's

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[305] H. S. W. Massey, J. Wylie, R. A. Buckingham, and R. Sullivan, 'A Small-scale Differential Analyser: Its Construction and Operation,' *Proceedings of the Royal Irish Academy*, *Section A*, Vol. 45, (1938), p. 21.
[306] D. Bates, R. Boyd, and D. G. Davis, 'Harrie Stewart Wilson Massey, 16 May 1908 – 27 November 1983,' *Biographical Memoirs of Fellows of the Royal Society*, Vol. 30, (1984), pp. 444–511.

model the *Meccano Magazine* with pulleys and belts, and removed the torque amplifiers in his final design (see figure 3.16).[307]

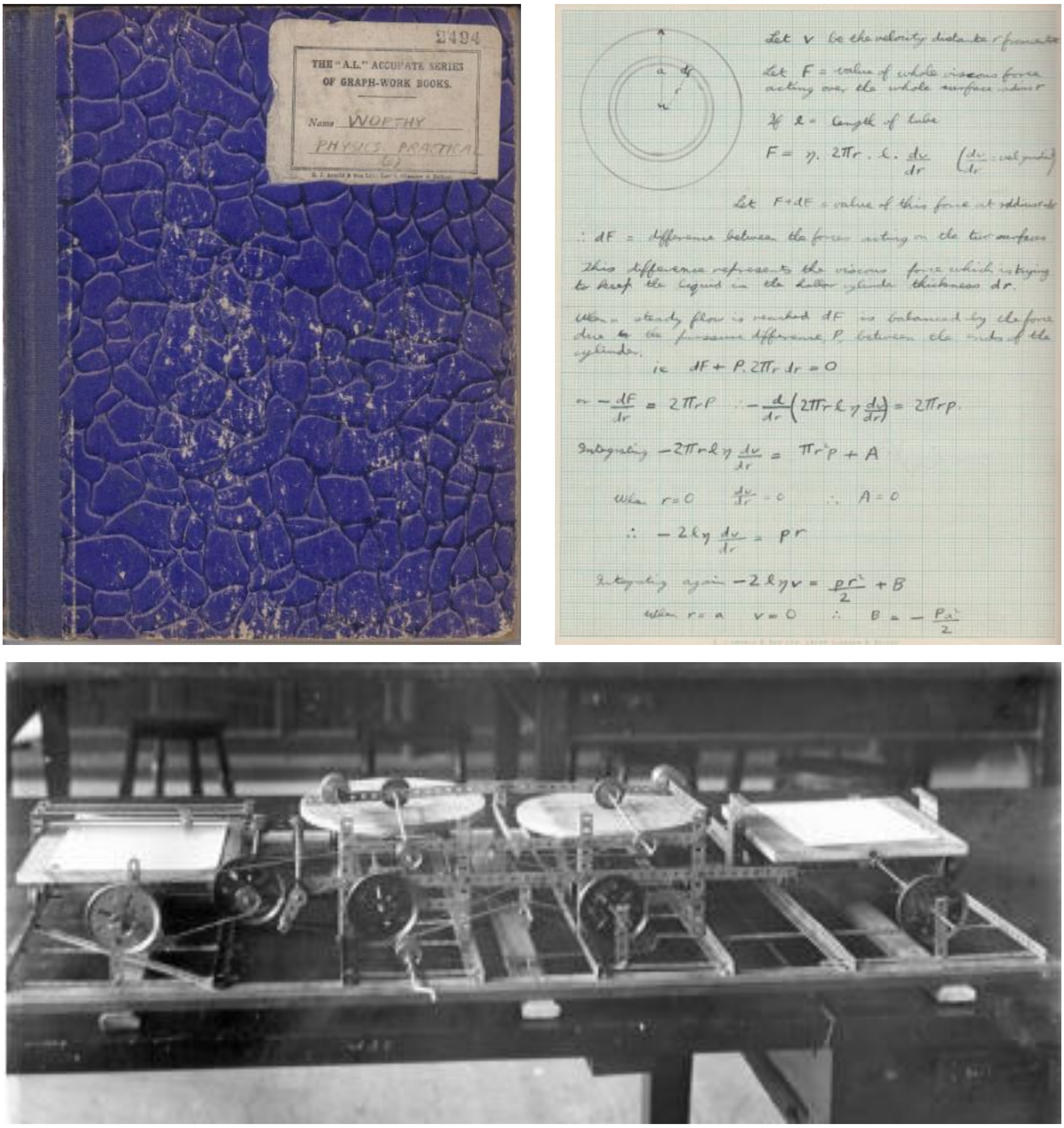

Figure 3.16: The top two images are of William Worthy's notebooks, while the bottom image shows the differential analyser he constructed from Meccano. His design uses a pulley system and does not have torque amplifiers. (© Pocklington School Archives).

These design choices also demonstrate some of the negative impacts that Hawks' 'Meccano-fication' of Hartree and Porter's object had for those who attempted to rebuild these objects, which were not as simple as the magazine implied. These changes meant that his analyser

[307] Pocklington School Archives, York, W. D. Worthy, 'Physics Practical Notebook.'

had a much lower accuracy rate than other differential analysers and could not produce quantitative results. Despite not being used during the Second World War, it was subsequently used as a teaching model to demonstrate the principles of differential analysis.[308]

Hartree describes another Meccano differential analyser constructed by a group of schoolboys in his article ‘The Mechanical Integration of Differential Equations’ (1938).[309] However, there are no further details about this model, its designs, or applications, except that it was constructed at Macclesfield Grammar School by a teacher, Roger Stone, and used as a teaching device. These two stories confirm the need to approach these analogue machines as objects in their own right, and not as part of a broader, homogenous category of ‘analogue computers’ that were a precursor technology to digital methods. In Worthy’s case, his machine was developed ‘for fun,’ before being used as a teaching tool, while in Stone’s case, his machine was developed as a teaching tool, and was never intended to be used as a mathematical machine or research tool.

Another example was from Robert Beard, a Fellow of the Institute of Actuaries, who built a six-integrator non-Meccano differential analyser in 1939 (see figure 3.17). He received advice from Hartree and Massey on how to build the machine, which had been funded by the Institute of Actuaries. The analyser was applied to the problems of calculating different actuarial functions, which included whole-life policy values, annual premiums, annuities, interest, and pension fund derivatives.[310]

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[308] T. Robinson, ‘The Meccano Set Computers: A History of Differential Analysers made from Children's Toys,’ *IEEE Control Systems Magazine*, Vol. 25 (3), (June, 2005) p. 29.

[309] D. R. Hartree, ‘The Mechanical Integration of Differential Equations,’ *The Mathematical Gazette*, Vol. 22 (251), (October, 1938), pp. 342-364.

[310] R. E. Beard, ‘The Construction of a Small-scale Differential Analyser and Its Application to the Calculation of Actuarial Functions,’ *Journal of the Institute of Actuaries*, Vol. 71 (2), (March, 1942), pp. 193-227.

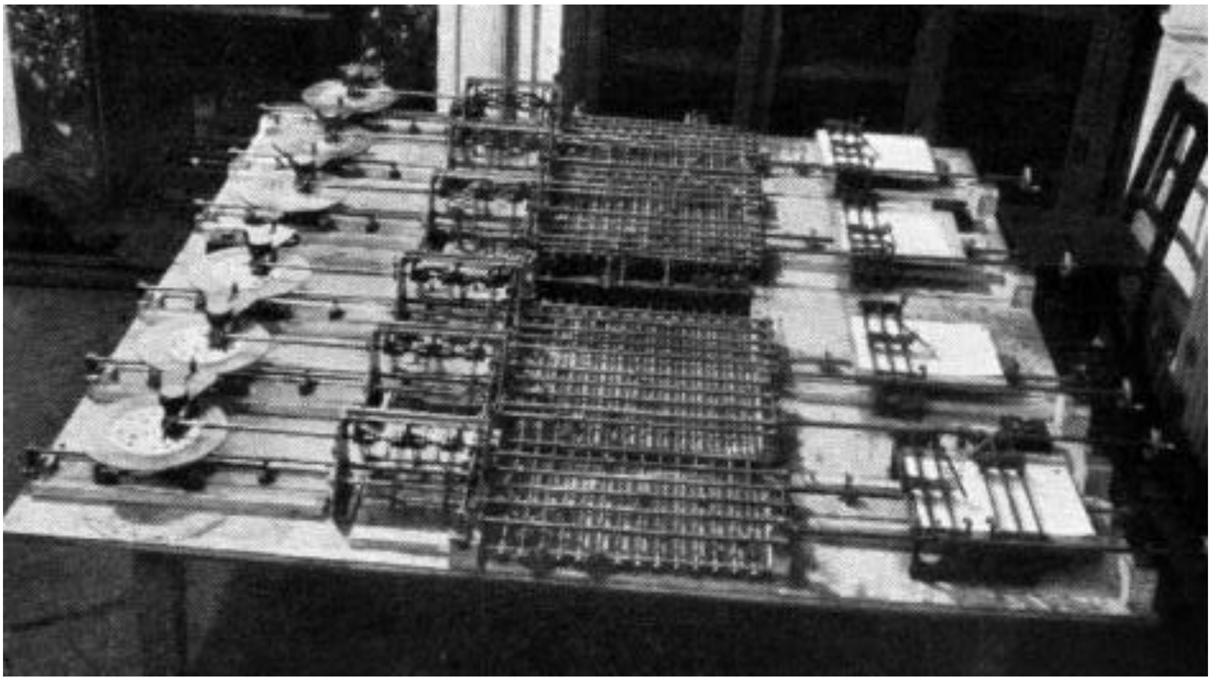

Figure 3.17: An image of R. E. Beard's six-integrator differential analyser, built for the Institute of Actuaries. (Image reproduced from R. E. Beard, 'The Construction of a Small-scale Differential Analyser and its Application to the Calculation of Actuarial Functions,' *Journal of the Institute of Actuaries*, Vol. 71 (2), (March 1942), plate three).

Despite having a limited accuracy rate compared to the Manchester and Cambridge analysers, it was requisitioned by Valve Research Department of Standard Telephones and Cables in 1940. It was applied to equations relating to work on the British aerial bombing system 'Oboe,' radar and navigational development, and aerial communications, before being disposed of in 1945.[311] Beard's analyser further confirms the importance of understanding the variety of contexts in which these machines were used, with the different pre-war analysers helping to demonstrate the breadth of applications – as modelling and teaching devices – that these machines had before and during the Second World War.

John Womersley developed a Meccano differential analyser in 1940 after being recruited by the Armaments Research Department (ARD) to work on internal ballistics. Womersley had worked with Hartree before the war, using the Manchester machine to

[311] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

publish a paper about the numerical integration of partial-differential equations.[312] He used this relationship with Hartree to construct his analyser, which he believed would enhance his work on general computation and on mathematics and statistics as applied to cordite and ammunition proofing.[313] However, just as Womersley came close to finishing the machine in September 1940, it was destroyed in the first air raid of the Blitz. Despite this setback, Womersley continued to perform mathematical analyses of internal ballistics and publish papers on differential analysis until 1942, when he was promoted to the Assistant Director of Scientific Research at the Ministry of Supply.[314]

There were another two Meccano differential analysers constructed during the Second World War. The first was constructed by John Benson at the Coast Artillery Experimental Establishment, while the second was built by Robert Sloane at the Air Defence Research and Development Establishment. Both of these analysers were used to help model systems that improved the fire control of artillery and anti-aircraft guns during the war, before being dismantled before the end of the war.[315] When compared to other objects developed in this period, these three analysers were designed and used primarily as engineering objects, with specific purposes and aims as mathematical machines and research instruments.

The final two differential analysers built in Britain during the Second World War were constructed by A. M. Wood, a Masters student at the University of Birmingham, and Nicholas Eyres, a member of Hartree's 'job shop'. Wood's non-Meccano design included six integrators and was constructed for his MSc thesis in 1942; he used it to resolve equations relating to his

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[312] D. R. Hartree and J. R. Womersley, 'A Method for the Numerical or Mechanical Solution of Certain Types of Partial-Differential Equations,' *Proceedings of the Royal Society A*, (1937), pp. 353-366.
[313] B. E. Carpenter, and R. W. Doran, 'John Womersley: Applied Mathematician and Pioneer of Modern Computing,' *IEEE Annals of the History of Computing*, (2014), p. 61.
[314] Ibid., p. 62.
[315] D. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

work on electrical engineering, before dismantling it.[316] His supervisor on this project was Rudolf Peierls, who utilised Hartree's Manchester machine for his work on the Tube Alloys project the following year. Eyres constructed a two-integrator Meccano analyser to use as a teaching tool during his time as a teacher at Radley College (see figure 3.18). He described how his machine was useful to teach with as the 'comparatively good results make it well worth constructing for demonstration methods.' He also described how the 'visual appeal of the [mathematics] when represented mechanically is considerable.'[317] Eyres's son, Peter Vaughan contacted me via the Meccanomen on 22 April 2018 to discuss a suitable location for the – recently rediscovered – analyser to be donated and kept; the most recent plan that we have discussed is for the machine to be moved to Bletchley Park.

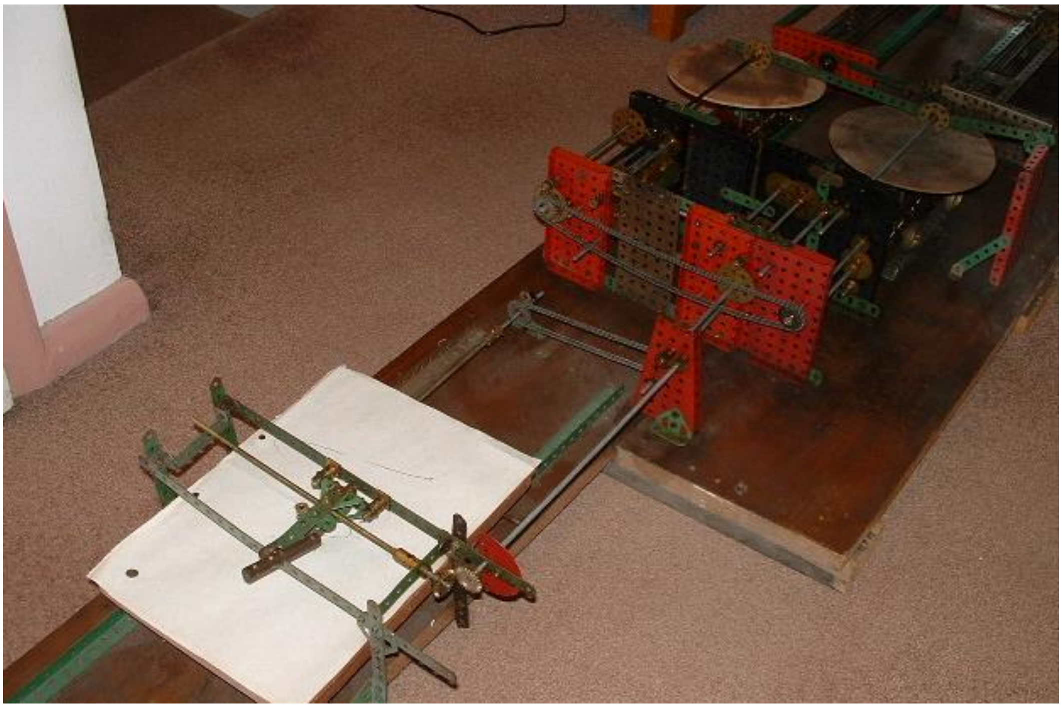

Figure 3.18: An image of the recently rediscovered two-integrator Eyres model. (Image reproduced from Eyres family personal collection).

[316] A. M. Wood, '*The Design and Construction of a Small-scale Differential Analyser and its Application to the Solution of a Differential Equation*,' (MSc. Thesis, University of Birmingham, 1942).

[317] N. R. Eyres, '220. Meccano in the Classroom,' *The Mathematical Gazette*, Vol. 54 (389), (October, 1970), p. 283.

A closer analysis of Eyres's teaching model demonstrates that it is still visibly configured to resolve an equation and has an output curve visible on the output table. A Meccanoman who has seen the model told me that it is still configured to demonstrate how an equation relating to motion and harmonics.[318] The decision to move this surviving Meccano object to Bletchley Park as an example of an early computer demonstrates the fluid nature of these objects' identities; especially when compared to the variety of stories that other surviving analysers are used to tell in museums today. Eyres's description of the performative nature of the analyser is also evident in the changes that Hartree made to the original differential analyser in 1947 when he rebuilt it into the Trainbox (see figure 3.19).[319]

Figure 3.19: An image is of the single-integrator Trainbox object, focusing on the torque amplifiers and integrating wheel-and-disc mechanism. (Image taken by author).

[318] John Barnes, personal communication, 29 April 2018.
[319] Eyres's son, Peter Vaughan contacted me via the Meccanomen on 22 April 2018 to discuss a suitable location for the –recently rediscovered – analyser to be donated and kept; the current plan that we have discussed is for the machine to be moved to Bletchley Park.

4. Conclusion

This chapter has collated the stories of analogue computing machines, using them to explore how the analogue method was applied 'to the solution of the technical problems paramount to war.'[320] The stories and changing applications of these machines highlight how the increasing complexity of computational equations during the war exposed the limitations of the mechanical method of the 'Mechanical Marvel,' and established that the end of the war did not signal the end of either the use of analogue methods or their usefulness.'[321] However, it also establishes how the understanding and application of analogue methods changed, and that they were a parallel computational method to digital computers, with larger differential analysers being used for modelling purposes, and smaller machines used to teach and demonstrate the mathematical principles of analogue computation. It also demonstrated that how each of these 'primary' analysers were used – as mathematical, research, or teaching objects – contrasts to how their identities have been changed in museums to tell different stories of engineering, mathematics, science, and computing. These contrasting stories attached to each of the analysers in museum exhibits allude to the continuation of the 'analogue gap' in how these objects are displayed, providing a useful context for the voice-based analysis of the Trainbox in Chapter Four.

The third section explored other amateur and professional machines that were constructed before and during the Second World War. The wartime and post-war use of these analogue machines for specific-purpose equations and teaching provide further case studies to support how analogue computational methods have been written about in the history of

[320] President Roosevelt letter to Vannevar Bush, 17 November 1944, https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm [accessed 21 March 2018].
[321] E. Hawks, and D. R. Hartree, 'Machine Solves Mathematical Problems: A Wonderful Meccano Mechanism,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 442.

computing since the millennium. While these stories make it apparent that digital methods offered clear advantages of speed and accuracy for research applications, they also highlight that the analogue machines remained significantly cheaper and more numerous. It was this usefulness in a modelling capacity that led to the construction of a series of electromechanical analysers after 1945 (see figure 3.20).

Date	Type	Materials	Location	No. of Integrators
1953	Mechanical	Non-Meccano	Building Research Establishment, (DSIR)	10
1954	Mechanical	Non-Meccano	Courtaulds Research Laboratories	8
1954	Mechanical	Non-Meccano	ICI, Butterworth Research Laboratories	6
1954	Mechanical	Non-Meccano	Royal Military College of Science	8
1954	Mechanical	Meccano	Royal Military College of Science	4
1954	Mechanical	Non-Meccano	Army Operation Research Group	6
1954	Mechanical (Former Manchester machine. Removed in 1954)	Non-Meccano	National Physical Laboratory	8
1954	Electro-mechanical	Non-Meccano	National Physical Laboratory	20
1955	Electro-mechanical	Non-Meccano	Radar Research Establishment	4
1956	Electro-mechanical	Non-Meccano	Royal Aircraft Establishment	6
1956	Electro-mechanical	Non-Meccano	Elliot Bros, Research Laboratories	6

Figure 3.20: A table of the differential analysers used after the Second World War, indicating their final year of use. (Data reproduced from A. J. Knight, 'A Survey of Computing Facilities in the UK (2nd ed.),' *Directorate of Weapons Research Report No. 5/56*, Ministry of Supply, London, August 1956).

Hartree included a chapter on these machines 'Useful Applications of the Differential Analysers' in *Calculating Instruments and Machines* (1949). He described how the specific applications of these post-war analogue machines included the 'motion of electrified particles in the magnetic field of the earth,' 'problems in non-linear electrical circuits,' 'chemical kinetics,' and 'running times of railroad trains.'[322] At the same time as writing this book about the larger post-war analysers and digital methods, Hartree cannibalised parts of the original Meccano analyser to construct a single integrating unit, which he configured for the 'tractive force equation as applied to railways.'[323] Similar to Worthy, Eyres, and others before him, Hartree redesigned the Trainbox as a limited version of a full analyser, without an input or output table, which allowed him to use it as a teaching device that demonstrated the mathematical principles of the wheel-and-disc integrator (see figure 3.21).

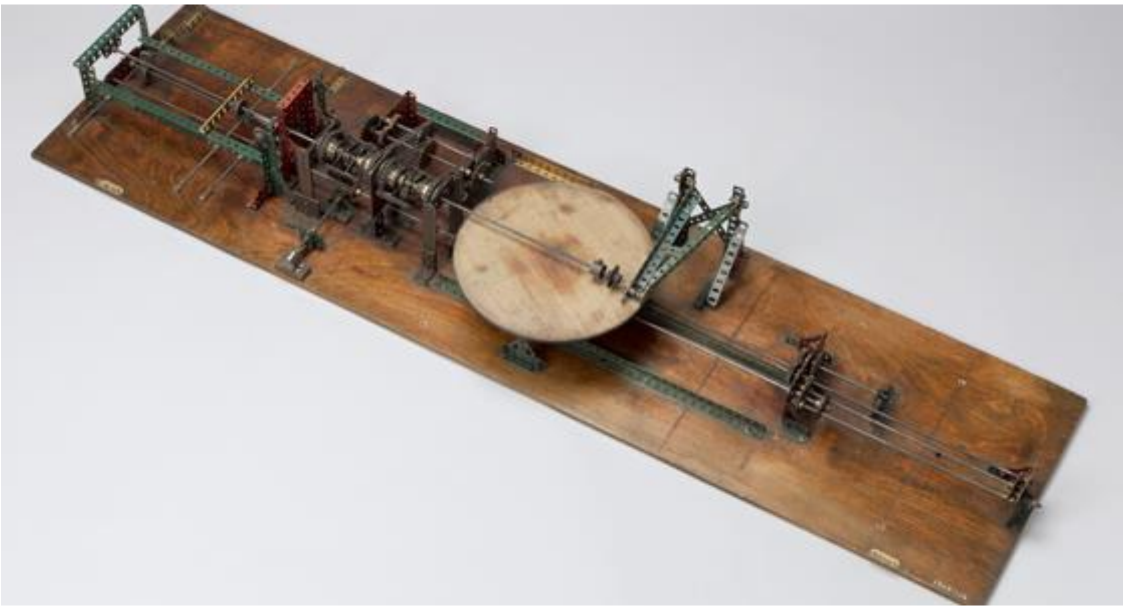

Figure 3.21: An image of the single-integrator Trainbox model rebuilt by Douglas Hartree in 1947 using Meccano parts taken from his original 1934 Differential Analyser. This object currently sits in the Web Exhibit of the *Information Age* gallery. (Image reproduced from Science Museum Archives, Sc. M. 1949-134).

The tractive force equation Hartree programmed into the analyser would have been used on a full analyser to calculate the effort required to move a train from a stationary position (which led to it being named the 'Trainbox').

$$T = \frac{d^2sp}{w} x \ 0.85$$

[322] D. R. Hartree, *Calculating Instruments and Machines* (University of Illinois Press, 1949), p. 25.
[323] Science Museum Archives, Sc. M. 1949-134/4, 'Pugh reflection report after trip to Michel at the National Physical Laboratory, 7 February 1974.'

This equation provided a real-world example that he could use to demonstrate the performative nature of the Trainbox, while teaching calculus in a mechanical way. Similar to Hartree, Bush also believed his MIT differential analyser was a useful teaching device as it allowed people to '...think straight in the midst of complexity.'[324]

It was during his tour of the Trainbox around the UK that Henry Calvert (Curator of Mathematics and Calculating Machines at the Science Museum) first contacted Hartree about a short-term loan of the Trainbox to help the museum tell the story of analogue computing. Hartree described in a letter to Calvert in 1950 how he had used the Trainbox to demonstrate 'all the main principles – of the first working [analyser] in Britain' at universities around the country.[325] He explained how he had changed the original differential analyser to the Trainbox by rebuilding it and placing it in a glass case, which gave him the ability to transport it around the country and easily demonstrate how the different units of the machine worked as they integrated the tractive force equation.[326]

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[324] V. Bush, *Pieces of the Action* (New York, 1970), p. 262; and V. Bush, 'Mechanical Solutions of Engineering Problems,' *Tech Engineering News*, Vol. 9, (1928).
[325] Science Museum Archives, Sc. M. 1949-134/3, 'Hartree letter to Calvert, 14 July 1949.'
[326] I. Allan, *British Railways Locomotives Combined Volume* (Ian Allan Ltd, 1957), p. 3.

Chapter Four – Ventriloquised Voices: The Science Museum and the Trainbox

1. Introduction

Museums are at the mercy of object availability. This challenge remains as applicable today as it was in 1949 when Henry Calvert (Curator of Mathematics and Calculating Machines at the Science Museum) first borrowed the 'Trainbox' version of Douglas Hartree's Differential Analyser from Hartree on a short-term loan.[327] The object borrowed and later collected by Calvert forms a good test case for the usefulness of the analogy of ventriloquism, presented below, as a way of understanding how different voices can be made to 'speak through' a museum object, as well as the long-term impact on the stories of that object. The Trainbox has been used by different curators at the Science Museum to tell very different stories since 1949. Thus, by using the Trainbox as an exemplar, this chapter will introduce and explain the ventriloquism analogy as it might apply to museum objects more generally. It will situate the concept within existing material culture literature, highlighting the varied ways in which the meaning and voices of objects are understood to change as part of a 'voice-based' theoretical approach to object analysis. A detailed investigation of how the object has been treated within the museum will demonstrate that the voices ventriloquised through the Trainbox were used to imbue it with physical and instrumental characteristics from previous versions

[327] Henry Calvert joined the Science Museum staff in 1934 and was appointed as the Curator of Mathematics and Calculating Machines before the Second World War. He worked at the Ministry of Supply during the war, calculating the terminal ballistics of projectiles. While in this role, he may have met Hartree who was based at the Servo Panel of the Ministry of Supply, where the successor to the original differential analyser had been put to work on various equations relating to the Allied war effort, calculating ballistics tables, plane trajectories, and explosive detonations. On returning to the Science Museum in 1949, Calvert was placed in charge of the Astronomy and Geophysics collections working on a series of projects, including authoring a catalogue on the museum's collection of scientific-instrument maker trading cards. Calvert later collected the original differential analyser (Science Museum Archives, Sc. M. 1949-134) on a short-term loan in 1949, before subsequently extending it.

of the machine. It will establish that these voices were often contradictory as the physical and instrumental functions of the object collected by the Science Museum are very different from those of the original object constructed by Hartree and Porter in 1934.

The second section of this chapter will briefly retell the origins of Hartree's 'Trainbox,' the object forming the core of the discussion in this chapter. The third section introduces the analogy of ventriloquism in the museum context, situating it within existing material culture literature. The fourth section interprets Calvert's correspondence relating to the original differential analyser from 1949-50. This correspondence shows how he began to turn the Trainbox into what he needed in the museum — a 'working model differential analyser' — by co-opting the voices of the physical and instrumental aspects of the 1934 object and ventriloquising them through the Trainbox.

To assess the longer-term impact of these incongruities, the fifth section analyses the correspondence of Jane Pugh (Assistant Keeper at the Science Museum) as it relates to the collection of the successor to Hartree and Porter's original differential analyser, the Manchester machine.[328] The sixth section explores subsequent re-interpretations of the story of the Trainbox and the various attempts made by the museum to ventriloquise new voices through the object between 1991 and 2003. It includes the establishment of the museum's Model Walkway in 2000 and discusses the impact of this and other curatorial ideas in relation to a 'universal language' of models.[329] The conclusion will discuss the author's personal experiences with the voices of the object in the museum, recognising that these have

[328] The Manchester machine was used by Hartree during his time at the Servo Panel for the Ministry of Supply throughout the war. The original Meccano Differential Analyser was not officially used for wartime purposes, but was instead kept in Hartree's personal study. After the war, the Manchester machine continued to be used by the National Physical Laboratory and eventually became available for collection in 1973, when half of it was collected by Jane Pugh at the Science Museum, with the other half being collected by the Science and Industry Museum in Manchester, where both parts remain today.
[329] Science Museum Informal Collection, D. Woodcock, 'Making the Modern World, Model Walkway Summary Document' (2000).

continued to evolve and change as the object is incorporated into its most recent home: the *Information Age* gallery (opened in 2016). This analysis of the Trainbox as it is currently displayed will demonstrate that it continues to speak to audiences with aspects of all of its ventriloquised voices, and is an example of a 'material polyglot.'

2. The Trainbox

After the Second World War, Hartree resumed his academic career at the University of Manchester, before being appointed Plummer Professor of Mathematical Physics at the University of Cambridge in 1946. As part of his move to Cambridge, the original Meccano differential analyser that he had built with Porter was dismantled, with Hartree salvaging some Meccano parts from the differential analyser and used them to rebuild a portion of the original model. He removed the input and output tables, turning this new version of the machine into a teaching device, which he used to demonstrate the principles of mechanical integration. Initially loaned to the Science Museum in 1949, it is the Trainbox that forms the subject of this chapter (see figure 4.1).

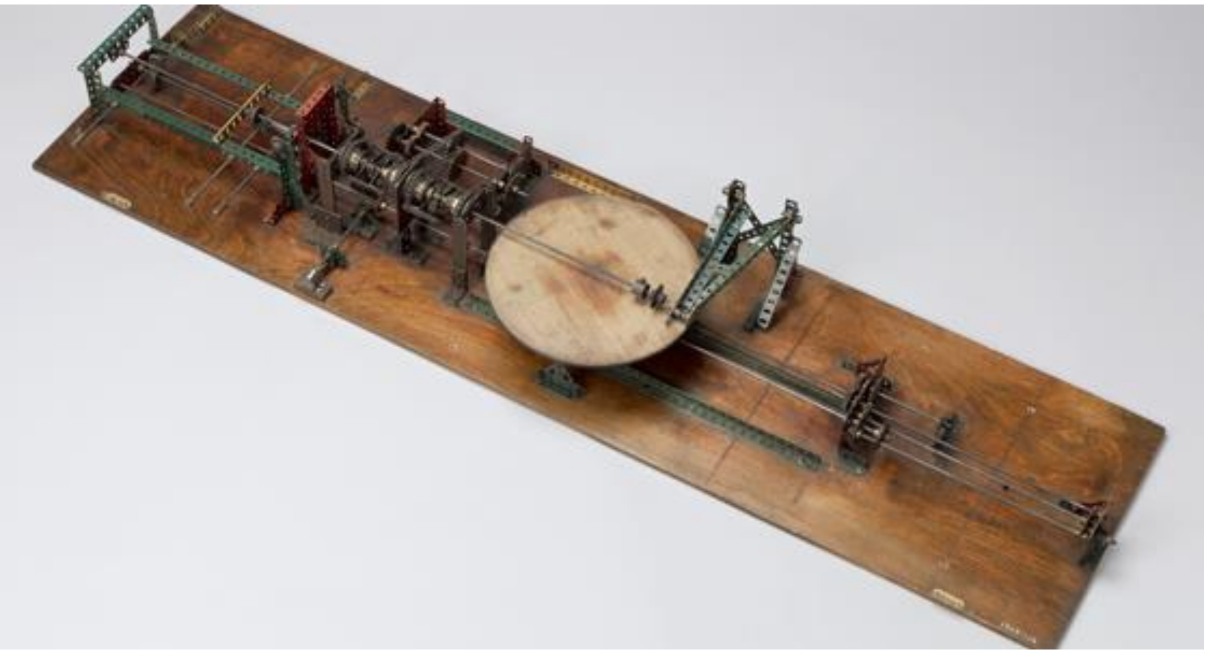

Figure 4.1: An image of the single-integrator Trainbox model rebuilt by Douglas Hartree in 1947 using Meccano parts taken from his original 1934 Differential Analyser. This object currently sits in the Web Exhibit of the *Information Age* gallery. (Image reproduced from Science Museum Archives, Sc. M. 1949-134).

3. Ventriloquism, Museums, and Objects

This chapter proposes the analogy of ventriloquism as a way of extending the discussion about how objects speak and tell different stories in museums. In a theatrical context, ventriloquism is a comedic convention that is seen and understood by audiences to be performed by the puppeteer, whom the audience willingly ignores.[330] There are limitations to this analogy — objects do not literally speak to audiences — these objects are essentially on a stage to be viewed and 'listened to' by visitors to the museum. There is also the question of whether museum visitors appreciate the processes that go into the curation of objects, compared to the theatrical context. However, while museum staff do not literally sit next to the Trainbox on display, I would argue that their presence behind the scenes in cultivating objects and editing their voices renders them as ventriloquists using puppets to speak to audiences.

While there are challenges to this analogy, this 'voice-based' analysis of the Hartree and Porter's original differential analyser allows us to explore how the different voices, stories, and physical and instrumental functions of the Trainbox have been changed in different contexts and circumstances within the museum. The functions I am concerned with here relate to the physical form of the object; the Trainbox had a single-integrating unit and no input or output tables, yet the voices ventriloquised through it indicated to audiences that it was a 'full-size' analyser. An example of the instrumental functions affected by this process includes the museum's description of the Trainbox as a 'working differential analyser' used during the Second World War, instead of a machine created from parts of the original in 1947.

[330] S. Connor, *Dumbstruck – A Cultural History of Ventriloquism* (Oxford University Press, 2000), pp. 3-5.

The ventriloquism of the voices of an object is distinct from the process of object re-interpretation, which is a necessary aspect of the work of museums, stemming from their core missions: to preserve objects and use them to educate their audiences, without destroying or damaging the object in the process.[331] However, as many of these objects cannot be physically altered or used in a way that risks damage, museums have to change the voices with which an object speaks to an audience. These new voices are often required because collected objects are either displayed in a static, 'non-working' way (to avoid damage), or have had parts changed or removed from them before their collection, altering their original physical and instrumental characteristics in the process. This leads these types of objects — including the original differential analyser — to be provided with new voices to evoke previous physical and instrumental aspects of the original version of the object. Interestingly, this analysis of the voices of the original differential analyser demonstrates that some of the new voices ventriloquised through the machine are not linked to previous aspects of the object but have been created to allow the object to tell new stories.

Samuel Alberti's 'Objects and the Museum' (2005) discusses the idea that objects have significant 'ages' relating to how their status and stories have changed during their careers in the museum.[332] The idea of ventriloquism builds upon Alberti's work by showing that original differential analyser has not been 'mute' or had a 'stable meaning' since it was collected by the museum in 1949, but instead has been encountered by collectors, curators, and audiences in diverse and varied ways.[333] Through exhibit labels, cataloguing information, and re-

[331] An example of this type of core mission when collecting objects can be observed in the policy documents of the Science Museum relating to the development of its collections:
Science Museum Group: 'SMG Collection Development Strategy,' https://group.sciencemuseum.org.uk/wp-content/uploads/2016/03/SMG-Collection-Development-Strategy.pdf [accessed 1 April 2017].
[332] S. J. M. M. Alberti, 'Objects and the Museum,' *Isis*, Vol. 96, (2005), p. 560.
[333] Ibid., pp. 560-562: 571.

interpretation by the museum, the Trainbox has gained a number of different voices, which are in continuous dialogue with its audiences in the *Information Age* gallery today.

The idea of objects 'speaking' was a development of the 'material turn' within material culture, which has its roots in the 1980s and has developed into the new century. Two examples of this literature are relevant to the focus in this chapter; the first is Christopher Tilley's *Metaphor and Material Culture* (1999), which explores the metaphorical meanings of objects and language, and the second is Lorraine Daston's book *Things That Talk: Object Lessons from Art and Science* (2004), in which she discusses objects that 'speak.'[334] Tilley's argument that material culture must be understood through metaphor in the same way as language invokes the idea that our understanding of objects as things is premised on the fact that they are highly malleable, according to the specific cultural factors and attributions we place upon them.[335] This type of semiotic approach to objects will feature in the analysis of the different versions of the original differential analyser in this chapter.

Complementing Tilley's ideas of object metaphor and language, Daston argues that the way in which an object speaks evolves, such that the changing contemporary meanings that we place on objects become compounded, eventually creating multiple layers of meaning. She explores her ideas using the example of Peacock Island (a world heritage site with a fairy-tale castle on an island in Berlin's Havel River), arguing that the layers of meaning present on the island are the result of a history of different cultural functions each of which leaves deep impressions in the landscape.[336] According to Daston, things talk in their 'own' voice, rather than merely repeating or playing back the human voice. Her assertion that our

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[334] C. Tilley, *Metaphor and Material Culture* (Blackwell Publishers, 1999); and L. Daston, *Things That Talk: Object Lessons from Art and Science* (Zone Books, 2004).
[335] C. Tilley, *Metaphor and Material Culture* (Blackwell Publishers, 1999), p. 14.
[336] L. Daston, *Things That Talk: Object Lessons from Art and Science* (Zone Books, 2004) p. 101.

understanding of objects (as 'loquacious palimpsests') is based on their layered meanings is central to the case study in this chapter, which argues that the differential analyser is an example of a 'material polyglot' that speaks to audiences with all of its voices at the same time.[337]

An alternative way of understanding how objects change in museums is by exploring the process of accessioning by which objects are classified and categorised when they are added to museum collections. In 2014, Jody Joy (Senior Curator of Archaeology and Anthropology at the University of Cambridge) described how the process of accessioning '...has the effect of resetting the biography of the object making it a very different thing as it becomes part of a museum collection.'[338] This interpretation of the process of accessioning — as a way of changing an object's narrative — is framed by the idea that objects have biographies. Ethnographic historians developed the idea of object biographies in the 1980s to explain the change in the identity of objects in specific cultural settings.[339]

However, there have been many critiques of this approach which suggest that this idea places too much emphasis on specific ethnographic identities of an object at the expense of its broader narrative, while also making the object a passive part of the subject/object dialectic.[340] It follows that using concepts of object biography to understand an accessioned object would place too large an emphasis on specific aspects of the object's identity at the expense of others. The example Joy uses is a Palaeolithic hand axe in the Cambridge gallery.

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[337] Ibid., p. 10-11.
[338] J. Joy, 'What do Museums do to Objects?' seminar transcript and recording available at: http://www.artandscienceofcuration.org.uk/curating-objects/ [accessed 15 December 2017].
[339] I. Kopytoff, 'The Cultural Biography of Things: Commoditisation as Process,' in., A. Appadurai, *The Social Life of Things: Commodities in Cultural Perspective* (Cambridge University Press, 1988), pp. 64-95.
[340] The critiques come from B. Latour, *We Have Never Been Modern*, trans. Catherine Porter (Harvard University Press, 1993); C. Pinney, 'Automonsters' in P. Wollen, and J. Kerr (eds.), *Autopia: Cars and Culture* (Reaktion Books, 2002); and K. Dannehl, 'Object Biographies' in K. Harvey (ed.), *History and Material Culture: A Student's Guide to Approaching Alternative Sources* (Routledge, 2009).

The label attached to the hand axe describes it as a ‘Hand axe knapped around [a] fossil shell, Palaeolithic (about 400,000 years ago), Elvedon, Suffolk.’[341] This object biography gives a time frame for when the object was made, describes its physical form, and gives a geographical location for where it was discovered. However, it does not attempt to tell the story of the object beyond these specific aspects, meaning that this is the only information that museum visitors will take from viewing it. As an alternative, contemporary material culture literature advocates that objects need to be approached as things that could (and should) ‘speak’ with their audiences.[342]

Eilean Hooper-Greenhill adopts a more ‘internal’ understanding of how objects change in museums in *Museums and the Shaping of Knowledge* (1992). Eschewing the role of external cultural changes, she asserts that the narratives of objects are dominated by policy shifts within the museum, such that by themselves, objects have no essential identity other than that which the museum gives to them.[343] Kevin Moore develops this argument in *Museum Management* (1994) by emphasising the importance of observing the governing documents of museums when trying to understand how and why the narratives of objects are changed.[344] However, this institutionally-focused approach to meanings change is as problematic as the exclusively culture-driven explanations explored above.[345] Both

[341] J. Joy, ‘What do Museums do to Objects?’ seminar transcript and recording available at: http://www.artandscienceofcuration.org.uk/curating-objects/ [accessed 15 December 2017].
[342] L. Daston, *Things That Talk: Object Lessons from Art and Science* (Zone Books, 2004).
[343] E. Hooper-Greenhill, *Museums and the Shaping of Knowledge* (Routledge, 1992), p. 191.
[344] K. Moore (ed.), *Museum Management* (Routledge, 1994), p. 23.
[345] Other examples of this internal museum-focused approach to understanding how objects change includes: J. Durant (ed.), *Museums and the Public Understanding of Science* (London: Science Museum, 1992); S. V. F. Butler, *Science and Technology Museums* (Leicester University Press, 1992); P. Findlen, *Possessing Nature: Museums, Collecting, and Scientific Culture in Early Modern Italy* (University of California Press, 1994); F. E. S. Kaplan (ed.), *Museums and the Making of ‘Ourselves’: The Role of Objects in National Identity* (Leicester University Press, 1996); S. MacDonald (ed.), *The Politics of Display, Museums, Science, Culture* (Routledge, 1998); and P. J. T. Morris, *Science for the Nation: Perspectives on the History of the Science Museum* (Palgrave Macmillan, 2010).

approaches rely on single factors as explanations for change, underplaying the agency of the object in the process. Where traditional literature has described objects collected by museums as being 'wrested from their setting and alienated to perform,' this chapter will argue that the opposite is true.[346] It will demonstrate that the Science Museum has imposed many different voices upon the original differential analyser in an attempt to place the object back into previous contexts, ventriloquising the voices and meanings of the object in the process.

[346] Pope-Hennessy, quoted in M. Hall, *On Display: A Design Grammar for Museums* (London, 1987), p. 11.

4. The 'Working Model': Calvert's Classification

The initial loan of the Trainbox Differential Analyser to the Science Museum in May 1949 led Henry Calvert to pen the first of many letters to Douglas Hartree regarding the museum's collection and reclassification of the object. Calvert's first letter to Hartree was written on 1 June 1949. In it, Calvert asks if he '...should...be right in saying that this model was the first working Differential Analyser in [Britain]...' and argues that if so, it deserved to 'be preserved.'[347] This part of Calvert's letter shares similarities with the mission statement of the Science Museum at the time, which called for the '...preservation of appliances which hold an honoured place in the progress of science.'[348] Calvert's wording '...should I be right…' implies that he had a suspicion that the Trainbox he had just collected did not speak with the same voices as the original 1934 object. After the war, Calvert had sought a significant differential analyser item for the Science Museum's collection, to help tell the story of analogue computing.

Therefore, his attempt to clarify whether the object was 'the first working differential analyser' was an example of a curator checking the voice of the Trainbox to see if it could tell the story of differential analysis that he required. In 1949, the locations of other differential analysers — similar to the original differential analyser and the Manchester machine — would not have been well known, with many having been destroyed in the Second World War or still in use.[349] With this in mind, Calvert's question regarding the provenance of the machine ('Should I be right in saying that this model was the first working Differential Analyser in this country?') takes on a new meaning. It appears to be an attempt to check whether the

[347] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 1 July 1949.'
[348] Terms of Reference of the Bell Committee, as cited by D. Follett, *The Rise of the Science Museum under Sir Henry Lyons* (Science Museum, 1978), p. 19.
[349] C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific Publishing, 2003).

Trainbox could tell the same story of differential analysers as the part of the Manchester machine he was also trying to collect. This is demonstrated further in the last paragraph of Calvert's first letter, in which he requests that Hartree or one of his students visit the museum to help 'put it in working order.'[350]

Hartree's reply on 7 July 1949 reads as an attempt to clarify Calvert's question of whether the object now in the museum's possession was the '...first working differential analyser [in Britain].'[351] Hartree began by asserting that while there is a link between the collected object and the 1934 object, they were not the same and that '...more accurately, what is preserved is a portion – enough to illustrate all the main principles – of the first working one in Britain.'[352] This confirms the physical and instrumental changes that Hartree made to the object when he rebuilt it in 1947, giving his perspective on what the Trainbox was, relative to the original object: in his view, it was no longer a 'working model differential analyser' as he had described the Meccano model in 1935.[353] Hartree intended the Trainbox to be a working model *of a* differential analyser, which could demonstrate the principles of mechanical integration using a single, pre-programmed calculation, implying that he moved the voices of the Trainbox away from the voice of the original differential analyser as a working machine.

The technical differences between the two incarnations of the original differential analyser are that the original object, built in 1934, had four distinct integrators, and an input and output table, while the Trainbox that Hartree rebuilt in 1947 had only a single integrator, and no input or output tables. The integrator was a central component of the original set of

[350] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 1 July 1949.'
[351] Science Museum Archives, Sc. M. 1949-134/3, 'Hartree letter to Calvert, 14 July 1949.'
[352] Science Museum Archives, Sc. M. 1949-134/3, 'Hartree letter to Calvert, 14 July 1949.'
[353] D. R. Hartree, and A. Porter, 'The Construction and Operation of a Model Differential Analyser,' *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, Vol. 79, (1934), pp. 51-84.

instrumental functions of the differential analyser, with the number of them indicating what type of differential equations it could solve. Having four integrators meant that the original object could solve anything up to a fourth-order differential equation, while the single integrator on the Trainbox meant that it could only be used to demonstrate how first-order differential equations are integrated (as it had no output table). The difference in function between the original analyser and the Trainbox is clear: one could resolve equations, the other could merely show how the object could resolve them. Understanding the importance of the integrator and the input and output tables in resolving differential equations helps to highlight the impact that their absence had on the voices of the rebuilt Trainbox. Hartree was aware of the different function of his rebuilt object without these tables, commenting that it could only 'demonstrate the main principles of the original.'[354] His choices when rebuilding the Trainbox changed the voices that it spoke to audiences. However, because the Trainbox could 'demonstrate the main principles of the original' object, it still retained some instrumental functions of the original 1934 object. It was these similar instrumental aspects allowed Calvert to ventriloquise the voices Hartree had created with the 1934 object through the Trainbox to tell the particular story of differential analysis he needed, demonstrating that the voices of the object have multiple sources.

This process began on 14 July 1949, when Calvert received a letter from Hartree explaining that through his discussions with John Womersley, the first Superintendent of the Mathematics Division at the National Physical Laboratory (NPL), he could confirm to Calvert that '[they would] probably want to keep their (full-size) d. a. for 3 or 4 years for institutional and training purposes.'[355] When it became clear that the Manchester machine would not be

[354] Science Museum Archives, Sc. M. 1949-134/3, 'Hartree letter to Calvert, 14 July 1949.'
[355] Science Museum Archives, Sc. M. 1949-134/3, 'Hartree letter to Calvert, 14 July 1949.'

available, Calvert used the object that he had in hand — the Trainbox — and began to ventriloquise the voices of the original object, so that the Trainbox could tell the story of a working differential analyser. He began to ventriloquise these voices on a loan request form sent to the Director of the Science Museum on 15 July 1949. The form stated that 'Professor Hartree...offers to lend *a* meccano model *of a* Differential Analyser to the Museum' (emphases added).[356] The emphasised words reveal that Calvert understood that the Trainbox was a just a 'portion of a differential analyser.' However, the rest of his loan request form demonstrates his attempts to ventriloquise the voices of the original object through the Trainbox. This is evident in how his description of the Trainbox changes from a model 'of a' Differential Analyser to:

> *This* meccano model *was the* first working Differential Analyser outside the USA…after Prof. Bush had built the machine...Prof. Hartree made *this working model* of it, which would actually solve equations (emphases added).[357]

Calvert's use of the demonstrative adjective 'this,' as well as the words 'was the' when describing the object's past, conflates the voices of the original differential analyser's physical and instrumental functions (the working model differential analyser) with those of the Trainbox (the working model *of a* differential analyser). This conflation continued in the next sentence of the loan form, which described how Hartree had built this 'working model.' This implies that what the museum had was the object Hartree had built in 1934 which could 'actually solve equations.'[358] Despite the incongruities that existed between the voices of the two objects, Calvert's ventriloquism served to collapse the physical and instrumental gap

[356] Science Museum Archives, Sc. M. 8640/1/1, 'Calvert letter to Director of Science Museum, 15 July 1949.'
[357] Science Museum Archives, Sc. M. 8640/1/1, 'Calvert letter to Director of Science Museum, 15 July 1949.'
[358] Science Museum Archives, Sc. M. 8640/1/1, 'Calvert letter to Director of Science Museum, 15 July 1949.'

between the instrumentality of the two objects, conflating them and presenting the original differential analyser and the Trainbox as the same thing. This is clear in Calvert's next sentence which describes how '...*this* working model demonstrated the usefulness of the machine and as a result, a large one was constructed at Manchester University' (emphasis added).[359]

Through this note, Calvert moved the voices of the Trainbox from being 'a portion' (as described by Hartree), through 'the meccano model of a differential analyser,' and the 'working model' that Hartree built in 1934, to, finally, an object that served as a 'proof-of-concept' for the Manchester machine. These alterations were made to allow Calvert to use the Trainbox to tell the story of differential analysis that he wanted to tell. His attempts to ventriloquise the voices of the object are also clear in a letter sent to the Director of the Science Museum, in which he explained that '...the usefulness of the model to the Museum would be to enable us to show it in operation to demonstrate the principles...Hitherto we have only exhibited photographs of the Manchester machine.'[360] In the same form, Calvert used the term 'in operation,' which implied the Trainbox was a 'working model.'[361] This contrasted with his use of the phrase 'demonstrate the principles' later in the form, which borrowed from Hartree's original set of voices for the Trainbox.[362]

A more significant challenge that Calvert faced was that the Trainbox had been broken down into components as part of the collection process in 1949. As a dismantled object, it could not speak with any of the voices of the original object that Hartree and Porter had built. This meant that despite the descriptions of these voices that Hartree had given to him, Calvert

[359] Science Museum Archives, Sc. M. 8640/1/1, 'Calvert letter to Director of Science Museum, 15 July 1949.'
[360] Science Museum Archives, Sc. M. 8640/1/1, 'Calvert letter to Director of Science Museum, 15 July 1949.'
[361] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 3 March 1950.'
[362] Science Museum Archives, Sc. M. 1949-134/3, 'Hartree letter to Calvert, 14 July 1949'

was unable to ventriloquise through them through the Trainbox. To resolve this issue, Calvert wrote to Hartree again on 3 March 1950 to remind him of the offer to visit the museum to '...put [the object] back in working order.'[363] Calvert's request reflected the way in which he had changed the voices of the Trainbox with his description of 'a Meccano model of the Differential Analyser,' supplanted by the statement in the following sentence that 'the *machine* is now installed in a case' (emphasis added).[364] Calvert's choice of the word 'machine' over 'model' appears not to be accidental here, but represents another way of transferring the physical and instrumental aspects of the original object (i.e., those relating to the physical form of the object and those relating to its function) to the Trainbox. This conclusion is reinforced in the rest of the sentence, which explains that '…the machine is now installed in a case and is ready to connect to the mains.'[365] The phrase 'ready to connect to the mains' demonstrates that although the object was missing an input and output table, which precluded it from being a 'working model,' Calvert was still attempting to ventriloquise the voices of the original 'working model' analyser through the Trainbox.

When Hartree did eventually visit the museum on 18 July 1950 (sudden bouts of sickness had prevented him twice previously from doing so), he spent two hours with Calvert showing him how each part of the Trainbox object functioned.[366] Based on the archival record available, this was the last interaction between Hartree and Calvert regarding the Trainbox until 1957, when a branch of the Institute of Physics in Manchester requested to borrow the object from the Science Museum. In the final letter that Hartree sent to Calvert on 5 April 1957, he regarded the '...meccano model differential analyser as entirely at the Museum's

[363] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 3 March 1950.'
[364] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 3 March 1950.'
[365] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 3 March 1950.'
[366] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert Internal Memorandum to the Director of Science Museum, 19 July 1950.'

disposal…' and that the loan request from the Manchester Institute of Physics had been at his suggestion.[367] He also offered his services to visit the museum to fix the model should it return with some minor damage.[368] However, Calvert never requested Hartree for help in repairing the differential analyser as Hartree died of heart failure on 12 February 1958 at Addenbrookes Hospital in Cambridge.[369]

This analysis of the correspondence between Calvert, Hartree, and the Director of the Science Museum demonstrates the various ways that Calvert used the process of accessioning to ventriloquise the instrumental and physical stories of the original differential analyser through the Trainbox. Through looking at Calvert's documentation and correspondence relating to the object in this period, it is apparent that the stories it was used to tell when on exhibition — were not consistent with the actual object on display. The next section will demonstrate that Calvert's accession of the object resulted in incongruous voices that passed onto future curators in the museum. It will explore how Jane Pugh (Assistant Keeper) tried to find a way to reconcile the ventriloquised voices of the analyser with the object in the museum's collection when creating the Mathematics and Computers gallery in 1973-1974.

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[367] Science Museum Archives, Sc. M. 8640/1/1, 'Hartree letter to Calvert, 5 April 1957.'

[368] Science Museum Archives, Sc. M. 8640/1/1, 'Hartree letter to Calvert, 5 April 1957.' Due to the particular loan status of the Trainbox when Calvert had first taken it on loan, it was not until 2003 that it was formally gifted to the museum by Douglas Hartree's son Richard Hartree.

[369] C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific Publishing, 2003).

5. The *Mathematics and Computers* gallery and the National Physical Laboratory

Jane Pugh wrote her first letter about the original differential analyser on 5 November 1973 to Jack Diamond (Professor at the Simon Engineering Laboratory at the University of Manchester). Her letter reflects the impact that Calvert had in changing the voices of the Trainbox, and the challenges that these new voices caused due to their incongruous relationship with the object's physical form.[370] Pugh explained to Diamond that a new gallery was in development at the Science Museum called 'Mathematics and Computers,' for which she enclosed a list of potential objects and the gallery layout (see figures 4.2a and 4.2b).

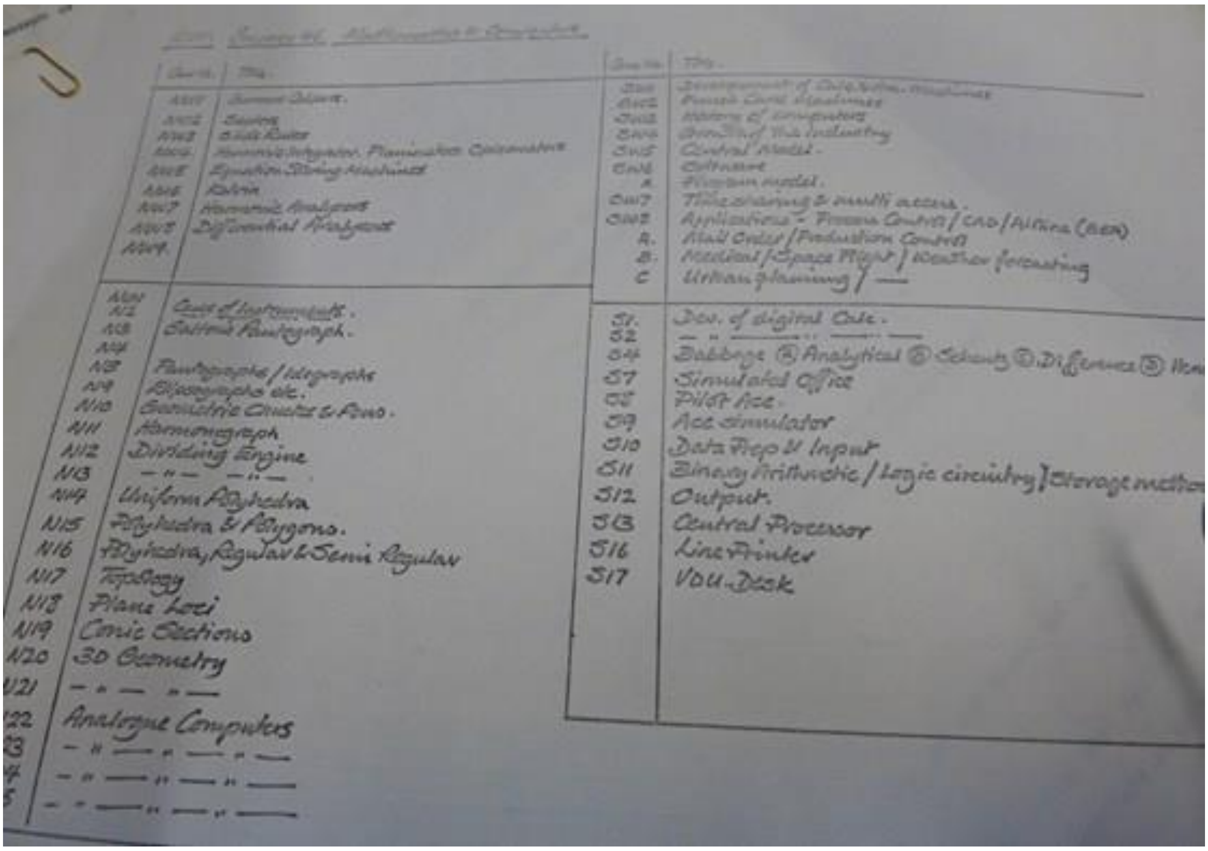

Figure 4.2a: The list of items in the *Mathematics and Computers* gallery. Point 54 (C) is the 'Trainbox.' (Image from MSO237/23 taken by author).

[370] Science and Industry Museum Archives, MSO237/26, 'Pugh letter to Professor J. Diamond at the Simon Engineering Lab, 5 November 1973.'

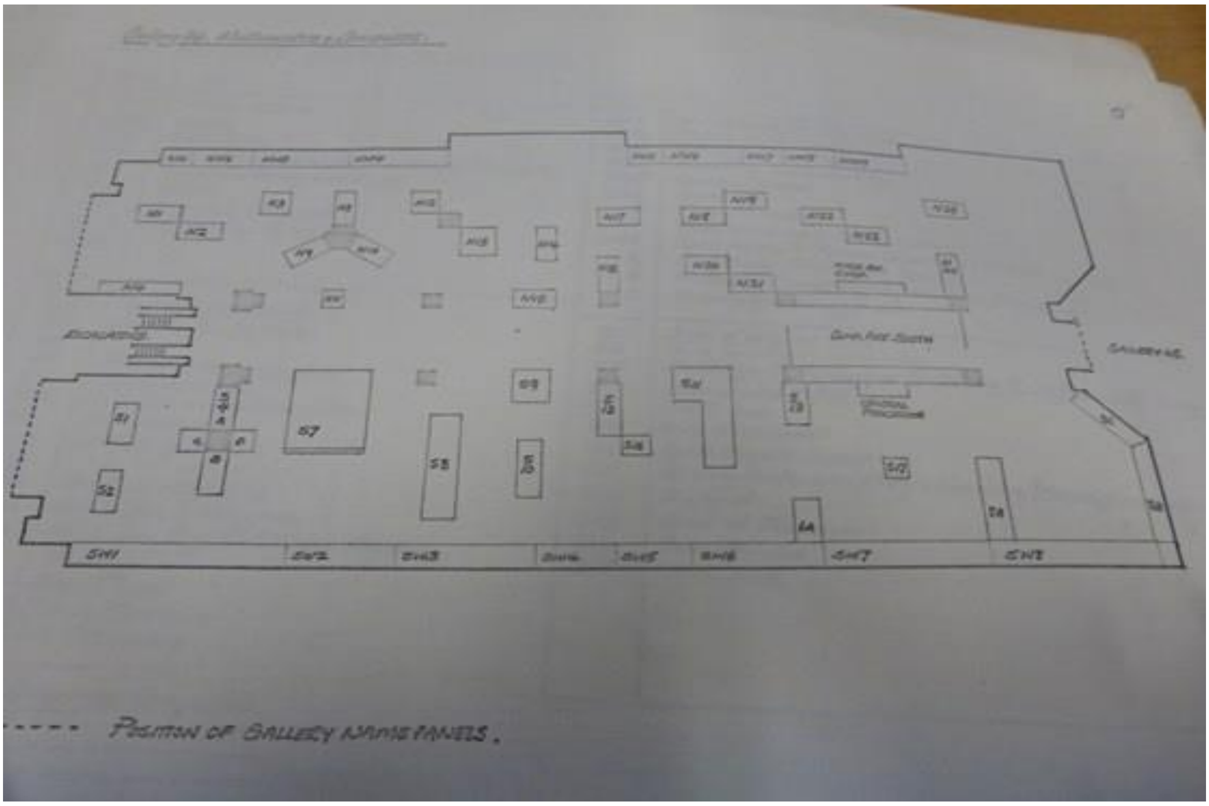

Figure 4.2b: The layout of the *Mathematics and Computers* gallery. The cross in the bottom left is where the differential analyser exhibit sat, as part of the 'Calculating Machines' section. (Image from MSO237/23 taken by author).

Pugh wrote that she had been searching for more pieces for the exhibition on differential analysers. However, the only success she had had was with 'Dr [Arthur] Porter [who had] kindly given [them] the logbook of the first large Manchester machine, and we already have a Meccano model differential analyser made by *Hartree and Porter*' (emphasis added).[371]

On the one hand, the language in the letter demonstrates the extent to which Calvert had changed the museum's understanding of the Trainbox. Pugh's phrase 'a Meccano model differential analyser made by Hartree and Porter' indicates that she thought the Trainbox was the original object that had been created in 1934 by Hartree and Porter, and not the model rebuilt in 1947 by Hartree. Her use of the phrase 'model differential analyser' also implies that at the 'hands-on' level in the museum, the voices of the original 1934 object had changed the

[371] Science and Industry Museum Archives, MSO237/26, 'Pugh letter to Professor J. Diamond at the Simon Engineering Lab, 5 November 1973.'

museum's internal understanding of the Trainbox. However, on the other hand, the rest of Pugh's letter hints at her knowledge that the voices attached to the object were incongruous with its form. She describes her intention to make the exhibit on differential analysers in the *Mathematics and Computers* gallery '…the only one of its kind in the country, immeasurably enhanced by addition of parts from the Manchester machine.'[372] This suggests an awareness that the Trainbox was not physically the same object as the 1934 model, and that the object could not be used to tell the stories of differential analysis that she wanted.[373]

Pugh's other correspondence from this period highlights that her concerns about the provenance of the Trainbox began after discussions with John Crank on the role the analysers had played in the Second World War. It was during these discussions that Crank had explained the differences between Hartree's and Porter's original model and the Trainbox that Hartree had created in 1947.[374] These conversations were what led Pugh to contact Arthur Porter to provide further context on his and Hartree's work. Porter replied, sending Pugh a series of papers, notes, and letters related to his work on the 1934 object as well as the Metropolitan Vickers Logbook that detailed the construction of the Manchester machine in 1935.[375] These sources described the original differential analyser as having both an input and output table that could resolve many differential equations and produce graphical outputs, which led Pugh to question the provenance of the Trainbox further.[376] To resolve these, she visited Jack

[372] Science and Industry Museum Archives, MSO237/26, 'Pugh letter to Professor J. Diamond at the Simon Engineering Lab, 5 November 1973.'
[373] Science and Industry Museum Archives, MSO237/26, 'Pugh letter to Professor J. Diamond at the Simon Engineering Lab, 5 November 1973.'
[374] Science Museum Archives, Sc. M. 1949-134/4, 'Pugh reflection report after trip to Michel at the National Physical Laboratory, 7 February 1974.'
[375] Science Museum Archives, Wroughton, MS474/2, 'Metropolitan Vickers Log Book 1936.'
[376] D. R. Hartree, and A. Porter, 'The Construction and Operation of a Model Differential Analyser,' *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, Vol. 79, (1934) pp. 51-84; and D. R. Hartree, *Differential Analyser: On the work of the S. R. A. Group*, Monograph, 17.502 (University of Manchester, 1946).

Michel (a former student of Hartree's) at the NPL to learn more about the work he had done with Hartree and about the use of the differential analyser during the war.[377] Michel's explanation made it clear to Pugh that the original differential analyser and the Trainbox were two distinct objects. This information was revelatory for Pugh, who wrote: 'This seems to be a very likely explanation! I had heard of Hartree's "train box" from Prof. Crank, but had not connected it with our Model!'[378] This disconnect in Pugh's understanding of the object demonstrates the success Calvert had in ventriloquising the voice of object and changing how it was subsequently understood and exhibited at the museum.

In contrast to Calvert's correspondence, it is essential to understand that Pugh's questions about the provenance of Trainbox represent her attempts to amend the voices of the Trainbox. However, the museum's success in collecting part of the Manchester machine in 1974 meant that Pugh also had an alternative way of telling the story of differential analysis. The handbook for the new *Mathematics and Computers* gallery contained very few details relating to the Trainbox object that was on display, focusing instead on the Manchester machine (see figure 4.3).

> As can be seen from the University of Manchester machine, rebuilt especially for this exhibition, early differential analysers were entirely mechanical, with integrators and other units interconnected by driving shafts.[379]

[377] Science Museum Archives, Sc. M. 1949-134/4, 'Pugh reflection report after trip to Michel at the National Physical Laboratory, 7 February 1974.'
[378] Science Museum Archives, Sc. M. 1949-134/4, 'Pugh reflection report after trip to Michel at the National Physical Laboratory, 7 February 1974.'
[379] Science and Industry Museum, MSO237/23, 'A Handbook for the *Mathematics and Computers* gallery, 'A Guide to Computing Then and Now.'

This focus on the Manchester machine is not surprising given the content of Pugh's reflective report on her attempts to recover the instrumental and physical functions of the Trainbox, which highlighted her understanding of the physicality of the Trainbox as a demonstration model and a single integrator connected to no other units, and not a 'working differential analyser.'[380] Despite Pugh's best efforts to reconcile the ventriloquised voices of the object, they continued to dominate subsequent interpretations of the analyser throughout the next two decades, until the establishment of the museum's Model Walkway in the year 2000.

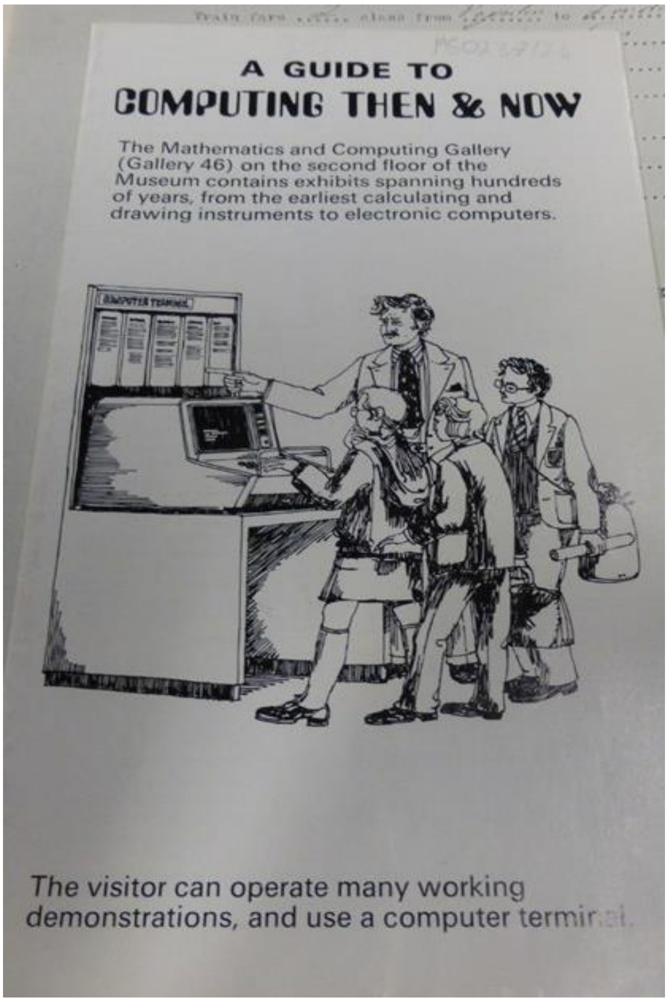

Figure 4.3: The front cover of the handbook given to visitors to the Science Museum's *Mathematics and Computers* gallery in 1974, a 'Guide to Computing Then and Now.' (Image from MSO237/23 taken by author).

[380] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 1 July 1949.'

6. Universal Language and the new 'Working Model'

Curator Doron Swade made handwritten notes on two letters about the original differential analyser received in 1991 and 1997. These notes and the museum's response to these letters highlight how, despite the re-display and re-interpretations of the object, past voices continued to create challenges and confuse the new voices with which the object was made to speak.

Swade's first note was scribbled on a letter written by Jenny Wetton, Curator of Science at the Science and Industry Museum, Manchester, on 27 November 1991. Wetton wrote regarding an object in the SIM stores that had been labelled as part of the Manchester machine.[381] Her letter enclosed a photograph of the object and requested the Science Museum's help in identifying it. The museum's response confirmed that it was not part of the Manchester machine, but perhaps more interestingly Swade's note reads: 'As I recall Diff An. is in process of transfer to Computing but presently remains with Maths.'[382] It is clear from this that the museum was in the process of separating the Trainbox and the Manchester machine to make them tell different stories. Swade also wrote a handwritten note on a letter received on 29 April 1997 from Peter Bunce (a visitor to the museum and self-confessed 'Meccano Boy'). Bunce's letter requested copies of the written materials that accompanied the Trainbox which was on display in the museum at the time.[383] Again, Swade wrote 'I believe that the Meccano Model of the Diff Analyser is in Maths, not Computing.'[384] Swade's notes

[381] Science Museum Archives, Sc. M. 1949-134/5, 'Wetton letter to the Science Museum, 27 November 1991.' The Science and Industry Museum in Manchester collected their half of the Manchester machine in 1988, returning it to working order in 1994, with the assistance of Charles Lindsay and volunteers from the Computer Conservation Society.
[382] Science Museum Archives, Sc. M. 1949-134/5, 'Swade Handwritten Note on the letter from Wetton to the Science Museum, 27 November 1991.'
[383] Science Museum Archives, Sc. M. 1949-134/5, 'Bunce letter to the Science Museum, 29 April 1997.'
[384] Science Museum Archives, Sc. M. 1949-134/5, 'Swade Handwritten Note on the letter from Bunce to the Science Museum, 29 April 1997.'

imply that the interpretation of the voices of the objects had changed, with the Manchester machine moving to the Computing gallery to tell the story of analogue computers, and the Trainbox being retained in the Mathematics gallery to tell the story of differential analysers. This type of re-interpretation of the stories of objects is a common practice in museums, as curators move objects between different contexts of categorisation and display. Despite this re-interpretation of the Trainbox as a mathematical rather than computing object, its ventriloquised voices — and the incongruities between them and the physical object — continued to impact the museum's understanding and presentation of the Trainbox, as is reflected in the museum's response to Bunce's letter.

The first document sent to Bunce was a copy of the label that accompanied the 1997 Trainbox display. The title of the label described the Trainbox as a: 'Single-integrator differential analyser made from Meccano,' echoing Calvert's 'working model' differential analyser.[385] By contrast, the label text explained that the object was '…constructed by Hartree as a demonstration model for use in lectures...used to solve problems of tractive force,' echoing the original voices of the Trainbox that Hartree built in 1947.[386] The incongruities between these two aspects of the label are further confused when Swade's handwritten description of the object as a 'Meccano model *of a* differential analyser' (emphasis added) on Bunce's initial letter is also considered. The contradiction between these different understandings of the Trainbox demonstrates that despite its re-interpretation by Pugh, it retained elements of the functions and voices created by Hartree and Calvert respectively.

Bunce was sent photocopies of the three articles on the original differential analyser from the June 1934 *Meccano Magazine*, an explanatory text on the methodological principles

[385] Science Museum Archives, Sc. M. 1949-134/3, 'Calvert letter to Hartree, 1 July 1949.'
[386] Science Museum Archives, Sc. M. 1949-134/2, 'Label for Science Museum exhibit, 'Single-integrator Differential Analyser made from Meccano.'

of differential analysis written in 1957, and a *Meccano Magazine* article from 1973. Taken together, these three reveal the complex identity of Trainbox. The 1934 *Meccano Magazine* articles described a '…remarkable Meccano mechanism...that solves complex mathematical problems with uncanny speed and accuracy,' reflecting the voices of the instrumental functions of the original differential analyser.[387] The explanatory text, written in 1957, describes the Trainbox as: '...mainly built from Meccano parts...the first effective general purpose "analogue" computer.'[388] This represents a different set of voices from the 1934 article and the 1997 object label, demonstrating that the museum's understanding of the object was still ultimately based on (and confused by) the voices that Calvert had ventriloquised through the Trainbox in 1949-50.

The 1973 *Meccano Magazine* article sent to Bunce further reveals the confusion over the status of the Trainbox in the museum. The article discussed the locations and continued use of both the original machine and the rebuilt Trainbox as if they were different objects:

> The exact facts are a little hazy...one of the machines - I do not know whether it was the original version - was taken to New Zealand… [and is] believed to be the sole survivor of the years…the first Meccano computer is still in existence, property of the Science Museum in London, although I have heard that the more interesting parts have been loaned to I. B. M.[389]

[387] E. Hawks, 'Meccano Aids Scientific Research,' *Meccano Magazine*, Vol XIX, No. 6, (June 1934), p. 441.
[388] Science Museum Archives, Sc. M. 1949-134/3, 'Differential Analyser Model, 10 October 1957.'
[389] C. J Jelley, 'Among the Model Builders with "Spanner,"' *Meccano Magazine*, Vol. 58, No. 3, (October 1973), pp. 54-55.

The assertion that the more 'interesting parts' of the original differential analyser were sent to I. B. M. is incorrect. It merely added to the confusing number of different stories and interpretations of the Trainbox based on its different voices.

Despite this lack of clarity, the creation of the Model Walkway in 2000 as part of the 'Making the Modern World' gallery—changed the museum's approach to the Trainbox and led to the development of a new set of voices. The permanent *Making of the Modern World* gallery was created in 2000 and is still open today. It places historical objects as part of a presentist chronological narrative in which objects are situated as part of the development towards modernity, rather than displayed within their original contexts. The Model Walkway is a long, raised display corridor overlooking the main gallery. It is one of four strands in the gallery, the other three being Technology in Everyday Life, Iconic Objects, and Themed Displays based around a chronology of technology from 1750 to the present day.[390]

The Model Walkway policy document describes a characteristic of models as things that speak a 'universal language.' The Walkway displays objects from 17th-century fire engines and 19th-century steam trains to 20th-century Barbie dolls, representing a miniature microcosm of the main 'Making the Modern World' gallery below, and encouraging visitors to think about the changing role of technology over time.[391] The notion that all models share a 'universal language' — as things that have 'many of the characteristics of the real objects,' albeit in miniature form — corresponds with the wider literature on models. This literature asserts that the general trend in museums has been a move towards using models in exhibits because they represent accurate reconstructions of larger or unobtainable objects and

[390] Science Museum Informal Collection, D. Woodcock, 'Making the Modern World, Model Walkway Summary Document' (2000).
[391] Science Museum Informal Collection, D. Woodcock, 'Making the Modern World, Model Walkway Summary Document' (2000).

machines.[392] Therefore, the creation of the Model Walkway implied that all models speak with a 'universal language,' which conveys the ways that they have changed, from tools of education and interpretation to forms of commercial persuasion and scientific confirmation, effectively ventriloquising a new voice through these objects in the process.

The use of models as material representations to support knowledge creation has been discussed by many historians.[393] Joshua Nall and Liba Taub assert in their chapter 'Three-Dimensional Models' that the value of three-dimensional models in history has been their use as representational objects that help people to understand and explain natural phenomena to audiences. They describe how models are a physical representation that bridges the immaterial and material, which help to mediate between scientific and public spaces.[394] The Trainbox object – and those that appear on the Model Walkway sit comfortably within this literature, through their use as objects that represent wider concepts. Soraya De Chadarevian and Hopwood assert in *Models: The Third Dimension of Science* (2004) that the use of models in science reduces the complexity of concepts, reconstituting sciences around 'visual languages and working objects.'[395] Similar to this, Daniela Bailer-Jones asserts in 'When Scientific Models Represent' (2003) how models can be used to entail propositions that are

[392] G. Kavanagh, *History Curatorship* (Leicester University Press, 1990), p. 43.
[393] D. M. Bailer-Jones, 'When Scientific Models Represent,' *International Studies in the Philosophy of Science*, Vol. 17 (1), (2003), pp. 59-74; F. E. S. Kaplan (ed.), *Museums and the Making of 'Ourselves': The Role of Objects in National Identity* (Leicester University Press, 1996); T. Knuuttila, '*Models, Representation, and Mediation' Philosophy of Science*, Vol. 72 (5), (2005), pp. 1260-1271; B. Lightman (ed.), *A Companion to the History of Science* (Wiley Blackwell, 2016); A. Pottage, 'Law Machines: Scale Models, Forensic Materiality and the Making of Modern Patent Law,' *Social Studies of Science*, Vol. 41 (5), (2011), pp. 621-643; M. Rossi, 'Fabricating Authenticity: Modelling a Whale at the American Museum of Natural History, 1906-1974,' *Isis*, Vol. 101 (2), (2010), pp. 338-361; and P. Wollen, and J. Kerr (eds.), *Autopia: Cars and Culture* (Reaktion Books, 2002).
[394] J. Nall, and L. Taub, 'Three-Dimensional Models' in B. Lightman (ed.), *A Companion to the History of Science* (Wiley Blackwell, 2016), pp. 572-586.
[395] S. de Chadarevian, and N. Hopwood (eds.), *Models: The Third Dimension of Science* (Stanford University Press, 2004), p. 2.

false where ‘the attempt to meet function overrides the striving for the model’s proximity to truth.’[396]

These models — whether historical or newly commissioned — serve a useful purpose in the Science Museum as they are understood to communicate realities of the material world that are too large or too small to be understood at a glance.[397] The distinctive mode of representation offered by models — as objects that have been employed in a variety of settings — invoke different ways of seeing, which allows audiences to appreciate the features of larger machines in miniature.[398] However, critics of the use of models in museums argue that taking models outside of the laboratory context can ‘lead to powerful fictions being constructed’; they argue that the lack of proper contextual information for models – when on display – can lead to a wide variety of interpretations that deviate from the original intention of the object.[399] Though not included directly as part of the interpretation of the Model Walkway, this new ‘universal language’ of models was discussed and accepted among museum staff and became part of a set of voices that the Trainbox was made to speak within its own display.

With the Trainbox now on permanent display, the Science Museum sought to formalise the terms of its stewardship of the object and potentially acquire it for its collections. A loan request form was initially sent by David Chalkley (Documentation Section of the Science Museum) to Douglas Hartree’s son Richard in 2003. The Trainbox’s new voices can ‘be heard’ within the form, with Chalkley designating it as a ‘Working model of a

[396] D. M. Bailer-Jones, ‘When Scientific Models Represent,’ *International Studies in the Philosophy of Science*, Vol. 17 (1), (2003), p. 70.
[397] Science Museum Informal Collection, D. Woodcock, ‘Making the Modern World, Model Walkway Summary Document’ (2000).
[398] S. de Chadarevian and N. Hopwood (eds.), *Models: The Third Dimension of Science*, pp. 39: 110.
[399] B. Lightman (ed.), *A Companion to the History of Science*, p. 577; and P. Vergo (ed.), *The New Museology* (Reaktion Books, 1989), p. 31.

differential analyser constructed from the construction toy "Meccano."'[400] In contrast to Calvert's own use of the phrase 'working model,' which referred back to the physical and instrumental aspects of the original 1934 model, this new use of the phrase 'working model' related to the universal language of the Model Walkway, which framed the Trainbox as a working model representation of the Manchester machine, albeit on a smaller scale.

This idea of the Trainbox as a smaller working model of a larger object echoes Pugh's description of the 'small Meccano d.a.' in 1974.[401] It is also possible to discern elements of Calvert's ventriloquised voices in Chalkley's designation of the Trainbox as a working differential analyser, rather than the 'portion' that Hartree had originally intended the object to be when he rebuilt it in 1947. This ventriloquising of the universal language of the Model Walkway's 'working model' through the object is another example of how the museum has changed the voices of the Trainbox. However, compared to previous voices, those relating to this new 'working model' were the first example of a set of voices that were external to the object. Hartree's voices were based on the changes he made to the object in 1947, Calvert's voices were a response to the need to make the object tell a certain story in 1949, and Pugh's voices were an attempt to better understand the provenance of the object in 1974 due to the contradictions of Hartree's and Calvert's different object voices. The Model Walkway ventriloquised a set of curatorial voices that emerged as an outcome of new museological concepts.

[400] Science Museum Archives, Sc. M. 1949-134/5, 'Science Museum Object Acquisition Form completed by Richard Hartree, 2003.'
[401] Science Museum Archives, Sc. M. 1949-134/4, 'Pugh reflection report from trip to Michel at the National Physical Laboratory, 7 February 1974.'

7. Conclusion: The Trainbox Today

Figure 4.4: An image of the Trainbox on exhibit today in the Science Museum's *Information Age* gallery. Note the order of the objects and the labels below the analyser, including a small picture of Douglas Hartree. (Image taken by Ben Russell).

In September 2015, on my first visit to the Science Museum, the Trainbox had been removed from exhibition in the Mathematics gallery in preparation for its move into the Web exhibit of the then-new *Information Age* gallery (see figure 4.4). While the object on display was the Trainbox that Douglas Hartree built in 1947, elements of its interpretation appear to be confused, with references made to it as either the Trainbox, the original Meccano model, the 'stopgap' before the Manchester machine, or the original differential analyser. The public history remains in the object on display today — in 2019 — that has a label, which reads 'A working model of a differential analyser, 1934.'[402] In contrast to previous displays of the Trainbox, which had focused on the central theme of differential analysis, the story that the object is used to tell in this exhibit is different, suggesting that within this re-interpretation,

[402] Label from *Information Age* gallery exhibit, image taken by author, 11 October 2016.

the object speaks with a new voice. To better understand what this voice is, we must understand that the Trainbox sits alongside five other objects in the following order:

(i) A model of the first transistor from 1947;

(ii) A paper on Boolean algebra and thermodynamics from 1948;

(iii) Alan Turing's work 'On computable numbers,' 1936;

(iv) A working model of a differential analyser, 1934; [the Trainbox]

(v) The logic door from a Ferranti Mark I computer, from 1951;

(vi) An image of Turing and colleagues working on the Ferranti Mark I, from 1951.[403]

A closer observation of the order of the objects and the labels in the exhibit shows that the Trainbox — despite being the earliest object chronologically — comes fourth in the order of display. In a Q+A session after a Research Seminar on the Differential Analyser I gave in October 2017, Tilly Blyth (Head of Collections and Principal Curator at the Science Museum) explained her perspective that the Trainbox – as part of the larger original differential analyser – was intended to represent Douglas Hartree's work and impact within the areas of both analogue and digital computing.[404] This story is evident on the label attached to the Trainbox, which is dedicated to the career of Douglas Hartree with both types of computers. However, as well as this label, there are others associated with the object, which demonstrate that the Trainbox – labelled as a 'working model of a differential analyser' – still speaks with some aspects of Calvert's original ventriloquised voice. One of these labels describes how 'Hartree built this model from the construction toy Meccano while waiting for a full-size analyser to be built.'[405]

[403] Label from *Information Age* gallery exhibit, image taken by author, 11 October 2016.
[404] T. Ritchie, 'Monstrous Models,' Research Seminar at the Science Museum, 31 October 2017.
[405] Label from *Information Age* gallery exhibit, image taken by author, 11 October 2016.

This label implies that the Trainbox was a type of 'stopgap' object developed before a full-size analyser (the Manchester machine) could be built, conflating the Trainbox with the original differential analyser that Hartree and Porter built in 1934, and that Hartree rebuilt into the Trainbox in 1947. The challenge of multiple interpretations is magnified when it is understood that this story attached to the Trainbox, which describes it as a 'stopgap' did not feature in either Hartree's original or Calvert's ventriloquised object voices. Instead, this interpretation is part of a new set of voices that have been ventriloquised through the object by the museum so that it can better tell the story of Hartree's broader career achievements in this exhibit in a linearly-related way.

This example demonstrates the incongruities that are caused when an object is made to speak with a number of simultaneous ventriloquised voices, which, through the introduction of new incongruous elements such as the 'stopgap,' further confuses the narrative of the Trainbox on display. The result is that while the label correctly attributes the construction of the object on display – the Trainbox – to Hartree who built it alone in 1947, it contradicts with the title given to the object – 'A working model of a differential analyser, 1934' – that implies that it is the original differential analyser Hartree had built with Arthur Porter in 1934. This means that despite the object on display very clearly being the Trainbox that was built in 1947, the ventriloquised voices that the object is made to speak with tell audiences different, often conflicting stories, simultaneously implying that the object is the original differential analyser, a working model, a 'stopgap' in preparation for the Manchester machine, and the Trainbox. The potential confusion caused by the addition of these new voices — to make the object tell different stories — supports that idea that the Science Museum's use of the Trainbox has '[led] to powerful fictions being constructed.'[406]

The analogy of ventriloquism has allowed us to explore how the voice of the object was changed on a number of occasions at a practical level to make it tell different stories, providing an alternative perspective on these changes. The demonstration of additional voices being ventriloquised through the Trainbox, supports the contention that it has become a 'material polyglot' in the *Information Age* gallery today, which simultaneously speaking to audiences with aspects of its original and different ventriloquised voices. However, while the analogy of ventriloquism is a useful tool to reframe how objects develop in the Science Museum, the idea of a museum object as a 'thing that talks' works just as well without it. Nevertheless, by using the analogy, the chapter has been able to move beyond separate discussions about accessioning, issues of space, and internal politics as explanations of the changing meanings of an object, instead presenting a more cohesive way of understanding how the ventriloquised voices persist, influence, and define subsequent reinterpretations, voices, and stories of that same object in a museum context.

[406] P. Vergo (ed.), *The New Museology* (Reaktion Books, 1989), p. 31.

Chapter Five – Meccano since the Second World War: From ‘Mainstream’ Meccano boys to ‘Alternative’ Meccanomen

1. Introduction

Chapter One challenged the conventional public history of Meccano as a synecdoche for British engineering. Through exploring how these different versions of Meccano were signified to readers of the *Meccano Magazine* before the Second World War, the chapter established that it did not have a synchronic public history.[407] It drew from aspects of Barthes' semiotic approach to demonstrated that this public history, along with Kroto's perspective of Meccano as a synecdoche for British engineering, and the previous academic histories of Meccano and the *Meccano Magazine*, had been based on an ‘imagined community’ of homogenous users.[408] Instead, it demonstrated that Meccano was changed from an educational toy to a training tool for would-be engineers, and then into an aspirational emblem of fan-participation in international science and engineering, before finally being made into an object with nationalistic overtones in the final years before the Second World War.

The Meccano story told in this chapter picks up from where Chapter One finished, exploring how Meccano has been changed since the Second World War. It establishes how the ‘mainstream’ version of Meccano and the *Meccano Magazine* were passed through the hands of different companies and publishers, which resulted in Meccano Ltd. going into administration in 1981. It also tells the parallel and intersecting story of how a group of former

[407] For more on these constructionist approaches to knowledge and meaning, refer to Chapter One, and the following references: R. Barthes, *The Elements of Semiology* (London, 1967); and R. Barthes, *Mythologies* (London, 1972).
[408] B. Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism* (Verso, 1983), p. 133.

Meccano boys – having grown discontented with the state of 'mainstream' Meccano – created their own 'alternative' version in 1965, based on their nostalgia for a 'golden age,' pre-war version of Meccano.[409] However, as the Meccanomen's 'alternative' version is based around the same pre-war, unchanged pieces of Meccano analysed in Chapter One, this chapter analyses and compares their shared and independent publications, groups, and organisations to their 'mainstream' counterparts. This helps to demonstrate how the individual clubs reshaped aspects of the 'golden age' version of their hobby to fit their nostalgia, before considering the impact these changes had on how the synchronic public history Meccano developed.

The self-published, independent publications of the Meccanomen have not previously been analysed alongside, or in contrast to, the 'mainstream' *Meccano Magazine*. The reasons for this are that many of these publications have been difficult to access in their entirety, while the Meccanomen have never previously been engaged with in a systematic way. However, through collaborating with the Meccanomen, this chapter tells the story of their hobby from both theirs and a historical perspective. Combining these perspectives provides a different way of approaching Meccano as a scientific-cultural object in the second half of the twentieth century.

Matthew Wale has written extensively about the value of independent publications in revealing the complex relationships between the members of the organisations that created them.[410] In his work, he analyses *The Naturalist* (1864-) (a publication of the Yorkshire Naturalist Union), using it to understand how different groups of members were brought

[409] D. Lowenthal, *The Past Is A Foreign Country – Revisited* (Cambridge University Press, 2015), p. 347.
[410] M. Wale and L. Beiermann, 'Self-Fashioning Scientific Identities: A Conference Report and Outlook,' *Constructing Scientific Communities*, (13 July, 2018).

together, given a sense of cohesion, and publicised their work beyond the North of England.[411] Another example of Wale's work is *The Entomologist* (1840-42, 1864-1973), in which he provides an insight into how this independent publication helped to remedy the lack of an entomological periodical after the demise of *The Intelligencer*.[412] This chapter broadly draws on these aspects Wale's work, using the *Meccanoman's Journal* (1965-1974) to explore and understand better the early years of the Meccanomen movement. It also uses the *Meccano Engineer*, various club journals and publications, and the *International Meccanoman* journal to understand how the 'alternative' version of Meccano continued to change after the demise of 'mainstream' Meccano in the UK in 1981.

The second section of this chapter establishes the demise of 'mainstream' Meccano after the Second World War until it was purchased by Lines Bros. in 1964. It uses Meccano outfits, instruction manuals, and the *Meccano Magazine* to explore the story of Meccano from the war until 1964, testing whether the changes made to the 'mainstream' version of the toy were a major factor that caused the Meccanomen to create their 'alternative' version in 1965.

The third section explores the 'New Look sets,' 'Themed Sets,' and 'Plastic Meccano' sets that Lines Bros. introduced and how these fundamentally changed the 'mainstream' version of Meccano, marginalising the Meccano boys in the process. It then explores how these users developed an 'alternative' version of Meccano in 1965 – through developing the Meccanoman's List, the *Meccanoman's Journal*, and the Midlands Meccano Guild – and how this changed them from what Mark Duffett calls 'passive consumers' into 'active participants'

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[411] M. Wale, 'The Entomologist's Record and Journal of Variation (1890-),' *Constructing Scientific Communities*, (8 June, 2018).
[412] M. Wale, 'The Naturalist (1864-),' *Constructing Scientific Communities*, (25 May, 2018).

in the context of their Meccano hobby.[413] These sections analyse how the Meccanomen initially used these publications, groups, and organisations to transport the values of what they called the 'golden age' of Meccano into another space, where they were both accessible and protected, a technique Grant McCracken has called a 'strategy of displaced meaning.'[414] It then draws on Duffett's two categories of participation by exploring how the early Meccanomen moved from creating spaces where they had the agency to articulate concerns about the 'forced conformity' of the 'mainstream' version, to spaces in which they re-imagined aspects of the past to create a 'golden age' users' version of Meccano.[415] However, it will highlight that from the beginning, the Meccanomen's version was based on their nostalgia for this 'golden age' of Meccano, rather than the different versions of pre-war Meccano as discussed in Chapter One.

The fourth section then explores how the 'mainstream' and 'alternative' versions of Meccano developed together until 1977, when the *Meccano Magazine*, with a Meccanoman as the editor for two issues, featured an article that described how the Meccanomen movement was fast approaching a 'golden age.'[416] It will explore how the different independent groups and publications were used to change the 'alternative' version, demonstrating that their version became increasingly complex as it was changed to 'meet the specific needs and desires' of nostalgic users. Daniel Cavicchi discusses this phenomenon of the 'fannish self' in his book *Tramps Like Us: Music and Meaning Among Springsteen Fans* (1998), asserting that fans are in a constant process self-discovery and that their fandom

[413] M. Duffett, *Understanding Fandom: An Introduction to the Study of Media Fan Culture* (Bloomsbury, 2013), p. 178.
[414] G. McCracken, *Culture and Consumption: New Approaches to the Symbolic Character of Consumer Goods and Activities* (Indiana University Press, 1990), p. 107.
[415] S. Stewart, 'Objects of Desire,' in S. M. Pearce (ed.), *Interpreting Objects and Collections* (Routledge, 2004), pp. 254-258.
[416] M. J. Walker, 'North-West Frontier,' *Meccano Magazine*, Vol. 62, No. 2 (April, 1977), p. 93.

becomes reshaped by its own reflexivity.[417] Drawing on Cavicchi, this section demonstrates that the 'golden age' of 'alternative' version of Meccano was reshaped by its own reflexivity, as the second-generation began to take over the Meccano clubs.

The fifth section tells the story of the 'mainstream' and 'alternative' versions after the collapse of Meccano Ltd. and the *Meccano Magazine* in 1981, including the formation of the *International Meccanoman* journal in 1988, and the International Society of Meccanomen in 1989. It analyses International Society of Meccanomen's claim that their 'golden age' 'Liverpool Meccano' was what 'Hornby would have wanted,' and compares it with the historical perspectives composed by the contemporary Meccanoman Matt Goodman.[418] It establishes that Goodman's perspective of the 'golden age' of Meccano does not fit with the conventional public history of Meccano, but that it is based on his personal experiences and the development of his 'fannish self.' The chapter finishes by comparing the two versions of Meccano that exist in the UK today, before asking the counterfactual question of which of these two versions Hornby would have wanted if he were alive.

[417] D. Cavicchi, *Tramps Like Us: Music and Meaning Among Springsteen Fans* (Oxford University Press, 1998), pp. 18: 136.
[418] J. Westwood, 'Editorial,' *International Meccanoman*, No. 1. (1988), p. 2

2. Meccano from the War to ’64

Historian Kenneth Brown, in *Factory of Dreams: A History of Meccano Ltd.* (2007) points to the failure of Meccano Ltd. to adjust to the more challenging trading environment of the 1960s as a major contributing factor in the demise of the Meccano.[419] Brown asserts that Meccano enjoyed an active and ‘undisputed mastery’ of its world for over half a century, but that as it evolved, the company became ‘increasingly outmoded.’[420] The main theme of his research is that Meccano began to fail in the late 1950s and 1960s. However, the Meccanomen have a different perspective. They assert that one of the major factors behind the failure of Meccano Ltd. – and the eventual creation of the Meccanomen movement – was that Meccano had ‘drifted gradually downhill’ since the Second World War.[421]

The final range of Meccano products developed before the Second World War was released in 1937. In contrast to the previous Meccano outfits (named using A-L), this new range included the larger No. 8, No. 9, and No. 10 Meccano outfits, which contained over 250 distinct parts. The models that featured in instruction manuals for these outfits were also new, with a much greater focus put on the use of the Meccano motor in models. These included the mechanised ‘Quayside Unloader,’ the ‘Overtype Stationary Engine and Boiler,’ and the ‘Traction Engine,’ which replaced all but the smallest models that had featured in the previous Meccano range.[422] However, during the same period, the Meccano instruction manuals began to be reduced in both size, quality, and model complexity. The smaller models

[419] K. D. Brown, *Factory of Dreams: A History of Meccano Ltd.,* (Crucible Books, 2007), pp. 3-6.
[420] K. D. Brown, ‘Death of a Dinosaur: Meccano of Liverpool, 1908-1979,’ *Business Archives: Sources and History*, Vol. 66, (1993), p. 35.
[421] J. Westwood, ’Editorial,’ *International Meccanoman*, No. 1. (1988).
[422] Meccano Instructions Manual, 1937, https://www.meccanoindex.co.uk/Mmanuals/1937/Manuals.php?id=1559407041 [accessed 20 March 2017].

were removed from the larger outfit booklets, while more complicated models were removed entirely, including the 'Drilling Machine,' the 'Steam Wagon,' and the 'Pithead Gear.'[423]

Alongside these changes, the onset of war led to a rationing of metal that reduced the availability of any new Meccano outfits. This problem was initially averted with the creation of a No. 000 outfit in 1940, which contained Meccano parts made from cardboard instead of metal. However, the subsequent shortage of paper meant that from 1941 to 1945, no new Meccano outfits were available for the Meccano boys to purchase.[424] This shortage also meant new instruction manuals ceased to be printed. In their place, surplus instruction manuals from the previous range (1934-37) were made available for the rest of the war. These had 'Special Notice' stickers on the front that told the Meccano boys that the plans inside the older manuals could be adapted to suit the newer Meccano outfits.[425] In comparison to the pre-war version of Meccano, the wartime version provided vastly reduced options for the Meccano boys to enjoy and explore.

The availability of the 1937 Meccano outfits gradually began to increase again once the war ended, with No. 0 to No. 5 outfits reintroduced in 1945, and No. 6 to No. 8 in 1946. However, the Meccano Instructions Manuals that accompanied these outfits were further reduced versions of those released in 1941 (before the paper shortage). When two versions of the manual are compared, the newer iteration contains no new models, instead featuring some that had been recycled from pre-1934 outfits. This is clear in the manuals as the plans for these models contained cross-hatched pieces that had been part of the 1934-37 outfits

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423 'Meccano 00-10 Outfit Models, 1937-1961,' https://www.meccanoindex.co.uk/Mmanuals/Pdf_disp1.php?Pdoc=Model37-61&id=1559407651 [accessed 20 June 2017].

424 'British Toy Manufacturer's Timeline,' https://www.vam.ac.uk/moc/british-toy-making-project/british-toy-manufacturers-timeline/#unique-identifier3 [accessed 17 December 2017].

425 'Meccano Mid-to-Late 1941 Manual Covers,' https://www.meccanoindex.co.uk/Mmanuals/1941/Covers.php?id=1559407651#nogo%22 [accessed 22 June 2017].

but had been removed from subsequent product ranges. Therefore, despite the re-release of Meccano outfits in 1945, the version of Meccano that users got was far more limited than the pre-war version, from which these sets and manuals had been recycled.

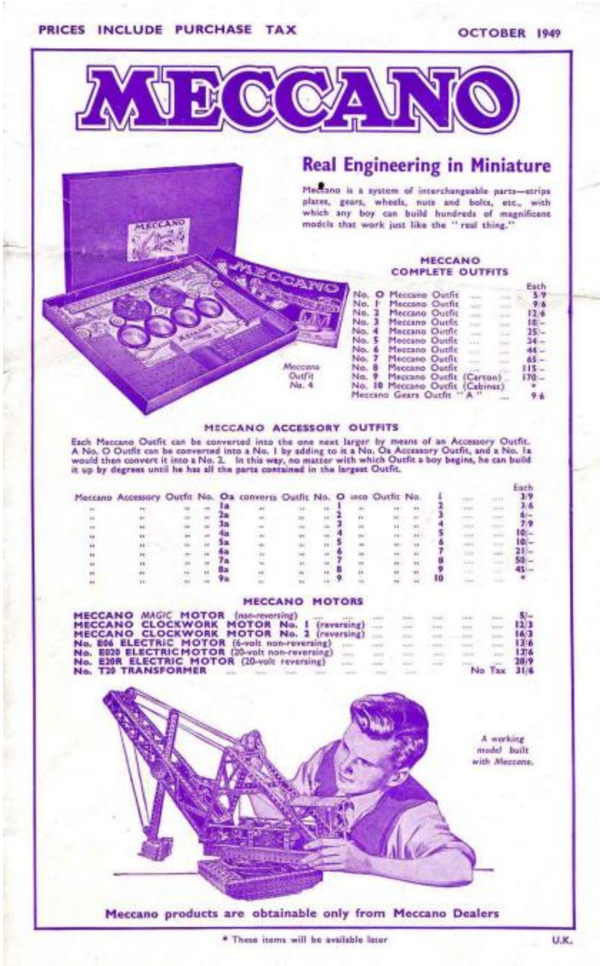
The *Meccano Magazine* also suffered from wartime and post-war fatigue, with the length and variation of articles dramatically decreasing. The focus of the magazine had changed as a result of the war, with the modelling content of the model-heavy issues in the 1930s being reduced to issues that contained modelling content on only two out of forty-eight pages.[426] Amongst the modelling articles that remained, the majority were either aimed at younger users, recycled from pre-war models, or both.[427] These changes would have made the post-war version of Meccano far less appealing for both current and potential users.

The release of a new range in 1948 was intended to reinvigorate the fortunes of Meccano. While it contained new products such as 'Magic motors' (a simple clockwork motor, designed for smaller models), the majority of models in the new instruction manuals still remained unchanged, with some still featuring recycled images that contained pre-1937

[426] *Meccano Magazine*, Vol. XXXI, No. 5, (May, 1946).

[427] It took until February 1946 for the red and green Meccano pieces to feature in a model in the magazine, despite being released the previous year. Even then, models continued to feature with cross-hatched pieces until 1947.

cross-hatched pieces.[428] For this new range, the tagline ‘Real Engineering in Miniature’ was replaced with ‘Toys of Quality’ in 1949 (see figure 5.1).



Figures 5.1: Two pages from subsequent instruction manuals. They both feature the same Meccano crane and outfits, but change the figure of the boy and these subtitles. The left image demonstrates that Meccano was ‘Real Engineering in Miniature,’ in 1949, before it was changed to ‘Toys of Quality’ in 1950. (Images reproduced from https://www.meccanoindex.co.uk/Cats/Products.php?id=1565445266).

These changes suggest that in contrast to the different types of Meccano in Chapter one, the post-war Meccano outfits, instruction manuals, and *Meccano Magazine* were used to turn Meccano (back) into a ‘boy’s toy.’ These post-war changes would have begun to marginalise the older Meccano boys, for whom Meccano was not simply a child’s toy.

[428] ‘New Meccano Models, Amusing Subjects Driven by *Magic* Motors’ found in *Meccano Magazine*, Vol. XXXIII, No. 7, (July, 1948), p. 238; and ‘Meccano 1948-1953 Overview,’ https://www.meccanoindex.co.uk/Mmanuals/1948/Intro.php?id=1559413397 [accessed 22 June 2017].

This failure of Meccano Ltd. to innovate their offering after the war, along with shortages of metal, and the decision to change Meccano back into a 'boy's toy' caused a gap to develop in the British toy industry in the early 1950s. This gap was exploited and filled by other products, including LEGO and Mattel, which introduced Hot Wheels sets in the UK during this period. The deregulation of international markets also caused an influx of foreign toys, in what was subsequently described as the 'Toy Boom.'[429] Along with the post-war changes to Meccano, these combined challenges led to an erosion in the number of Meccano users, with the readership of the *Meccano Magazine* dropping from over 70,000 in 1930 to less than 40,000 in 1950.[430] Despite this drop, the 'Toy Boom' was initially positive for Meccano Ltd, which experienced a brief revival in its finances.

This brief revival was based on the success of Meccano outfits that were released in 1954, containing updated pieces and new models. For those users that had been waiting for a new set of models to build since 1937, these new outfits and models would have been exciting. An analysis of the instruction manuals for these outfits highlights that they contained over 60% more new models when compared to the 1948 range.[431] However, Meccano Ltd. continued branding and marketing Meccano as a 'boy's toy,' which meant that this new range contained much simpler models than those that had characterised the Meccano outfits and manuals sold during the 1920s and 1930s. These new outfits also reverted to using similar images of boys to those featured on the early outfits of Mechanics Made Easy and Meccano. In place of the 'eminent engineer,' the 'Dad' character that Hornby had briefly used in the

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[429] Anon., 'British Toy Manufacturer's Timeline,' https://www.vam.ac.uk/moc/british-toy-making-project/british-toy-manufacturers-timeline/#unique-identifier3 [accessed 17 December 2017].
[430] P. Bowler, '*Meccano Magazine:* Boys' Toys and the Popularisation of Science in Early Twentieth-Century Britain,' *British Journal for the History of Science: Themes*, Vol. 3, (2018), p. 146.
[431] 'Meccano Manual Comparison,' https://www.meccanoindex.co.uk/Mmanuals/Updates.php?id=1560534541 [accessed 21 June 2017].

1910s returned, which would have signified to users that Meccano was a toy used by boys, and not their fathers (see figure 5.2).[432] These changes would have told the older Meccano boys (who increasingly had children of their own) that Meccano was a toy and that their role was to watch passively, rather than actively engage in the hobby.

Figure 5.2: The front cover of the No. 9 Outfit from 1954, which demonstrates how the role of the Meccano boys and their fathers had changed. The passive role of the father contrasts the former character of the active, 'eminent engineer.' (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1954/Intro.php?id=1560541082).

Although Meccano sales increased by 17% in the two years after the release of these outfits, they declined back to pre-1954 levels in 1960.[433] This initial decline (between 1956 and 1960) did not initially pose a problem for Meccano Ltd. as the sales of other Hornby products (Dinky Toys and Dublo Trains) compensated for the drop.[434] However, the continued

[432] R. Barthes, *Mythologies* (London, 1972), pp.116: 119.

[433] Liverpool Records Office, B/ME/6/1, Peat, Marwick, Mitchell, and Co., 'Annual Report: Meccano Limited And It's Subsidiary Companies,' (29 April, 1963), p. 12.

[434] This peak coincided for all of Meccano's products, including Dinky Toys and Hornby Dublo model trains, during a period referred to as the 'Toy Boom,' discussed in, Liverpool Records Office, B/ME/32/1, Anon., 'Meccano,' *Stock Exchange Gazette*, (18 December 1959).

influx of cheaper toys – from competitors such as Corgi Toys, and Triang Model Railways – also began to draw customers away from these other Hornby products. The result was that the sales of Hornby products decreased across the board after 1960.[435] Despite a new range being released in 1962, which returned to the names and images that Hawks had used in the 1920s and 1930s versions of Meccano, the continued use of the same trains, cranes, and car models meant that these attempts to reinvigorate Meccano came too late. Overall sales declined by 20% for Meccano Ltd. in 1963 alone, resulting in the company that had made Frank Hornby one million dollars being bought out by its biggest competitor, Lines Bros. in 1964.[436] This provides a useful contrast to Brown's perspective that Meccano Ltd. had an 'undisputed mastery' for over fifty years, highlighting instead that it began to have problems during the later years of the 1930s. In fact, the editorial of the *International Meccanoman* No. 1 in 1988 stated that this general decline of Meccano was one of four main reasons behind the formation of the Meccanomen movement in 1965.[437] Understanding that the 1930s was the 'peak' of Meccano before the war is important in helping to understand the context for why the Meccanomen initially created their 'alternative' version based on the red and green Meccano sets from 1934, which they believed was the 'golden age' of the toy.

[435] Liverpool Records Office, B/ME/6/1, Peat, Marwick, Mitchell, and Co., 'Annual Report: Meccano Limited And It's Subsidiary Companies,' (29 April, 1963), p. 12.
[436] M. P. Gould, *Frank Hornby: The Boy Who Made $1,000,000 with a Toy*, (Fredonia Books, 2004), Ch. 5.
[437] J. Westwood, 'Editorial,' *International Meccanoman*, No. 1. (1988), pp. 1-2.

3. Plastic Meccano and 'Obsolete Literature': 1964-1971

Lines Bros. made significant changes to try and restore Meccano's popularity after purchasing the company in 1964. They released 'New Look' sets that contained pieces painted yellow, black, and silver 'because these colours are now prevalent in the building world.' These adverts also asserted that the construction theme added an 'impressive air of realism to the whole range of Meccano models that boys can build' and represented a 'dynamic change in the presentation of the world's most famous construction system.' Users were also told that 'New Look Meccano' was a 'natural development of Frank Hornby's wonderful engineering toy.'[438] However, the biggest impact of these New Look sets was how they were used to change Meccano, turning it from an object associated with models that were 'engineering in miniature' into something aimed much more broadly at general hobbyists with an interest in practical 'construction in miniature' (see figure 5.3). These sets were another of the reasons given by the Meccanomen for the development of their alternative version.

[438] G. Byrom, 'Colourful Move by Meccano,' *Meccano Magazine*, Vol. 49, No. 6, (August, 1964), p. 32.

Figures 5.3: An advert for the 'New Look' Meccano sets that were repainted to represent real-world constructional tools. (Image reproduced from *Meccano Magazine*, Vol. 49, No. 6, (August, 1964)).

Another reason given was the changes made to the *Meccano Magazine* by Lines Bros. in 1964. In an attempt to save costs, they passed the management of the magazine to Thomas Skinner, and Co. Ltd, a publishing house outside of Meccano.[439] The first issue of the rebranded *Meccano Magazine* reflected the more generalist approach of New Look Meccano,

[439] G. Byrom, 'The Shape of '64,' *Meccano Magazine*, Vol. 49, No. 1, (March, 1964), p. 3.

with the previous Meccano tagline ('Toys of Quality') replaced with 'The Practical Boy's Hobbies Magazine.'[440] An article in the newly formatted magazine, titled 'The Shape of '64,' promised to 'introduce new articles and features – mostly covering model making and things you can make yourself.'[441] However, under Skinner and Co. Ltd., the number of Meccano models and articles in the magazine dropped, in favour of general interest articles on motor racing, soccer skills, and the children's science-fiction television programme *Fireball* XL5.[442] These changes were reflected in the new cover themes used from March 1964 to July 1967. Instead of depicting real-world engineering machines, photographs of various non-Meccano practical hobbies for boys, including karting and an image of a Wrenn 152 model car racing set (Scalextric) were used (see figure 5.4).[443]

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440 'Front Cover,' *Meccano Magazine*, Vol. 49, No. 1, (March, 1964). This contrasted with the previous subheadings of the magazine that had included: 'Published In The Interest Of Boys,' 'Helping Meccano Boys Have More Fun Than Other Boys,' and 'The Model World At Your Fingertips.'

441 G. Byrom, 'The Shape of '64,' *Meccano Magazine*, Vol. 49, No. 1, (March, 1964), p. 3.

442 G. Byrom, 'In This Issue,' *Meccano Magazine*, Vol. 49, No. 1, (March, 1964), p. 3.

443 These front covers featured in the: *Meccano Magazine*, Vol. 49, No. 2, (April, 1964); *Meccano Magazine*, Vol. 49, No. 3, (May, 1964); *Meccano Magazine*, Vol. 49, No. 7, (September, 1964); and *Meccano Magazine*, Vol. 49, No. 9, (November, 1964).

Figure 5.4: The two front covers at the top are from issues before the magazine was outsourced to Thomas Skinner and Co. Ltd., in March 1964. (Images reproduced from *Meccano Magazine*, Vol. XLVIII, No. 12, (December, 1963); and *Meccano Magazine*, Vol. XLVII, No. 14, (February, 1964). (Images reproduced from *Meccano Magazine*, Vol. 49, No. 2, (April, 1964); and *Meccano Magazine*, Vol. 49, No. 7, (September, 1964)).

In response to these changes, a group of older Meccano boys wrote to Geoffrey Byrom (the new editor of the *Meccano Magazine*), to express their dissatisfaction with the New Look sets and their desire to return to the previous version of Meccano and magazine format. Having spoken with contemporary Meccanomen about the authors of these letters, it appears that those who contacted Byrom were all aged over 45 years old. This supports the idea that it was these older Meccano boys, who would go on to create the Meccanomen, based around their childhood experiences with the 1920s and 1930s version of the toy. An example of this is Michael Laslett, who wrote that 'I like the *MECCANO MAGAZINE*, but I would like to see Fireside Fun back again. I like the bits about preserving old engines and models.' Another letter was sent in by Jonathan Nutman, who wrote 'As a regular reader of *MECCANO MAGAZINE*, I think to add pages about clothes, and pop artists and TV personalities would change a good magazine into a third-rate one.' Byrom printed Nutman's letter in the 'What's Your Problem' section of the magazine, alongside his response of '*YOU CAN'T PLEASE EVERYBODY*.'[444] His unsympathetic response contrasted with the way that Hornby had initially used the 'Our Mail Bag' section to regulate and support how different groups of users understood his two versions of Meccano half-a-century earlier.

In contrast to Hornby, who had engaged in a dialogue with Meccano boys to help them decide how best to use Meccano to reap its benefits (as either an educational toy or a training tool for would-be engineers), Byrom told users that the changes to Meccano had been decided by staff at Binns Road. When justifying these changes, he told users 'who should know better than the people who are actually designing and making Meccano?…a Meccano crane in yellow, black, and silver looks like the real thing, while a Meccano crane in red and

[444] G. Byrom, 'What's your problem?' *Meccano Magazine*, Vol. 49, No. 2, (April, 1964), p. 15.

green looks like – well – a Meccano crane.' The continued fall in popularity of Meccano products demonstrates that Lines Bros. had misunderstood what had made the pre-war range of Meccano popular.[445] Instead of different versions of Meccano designed to cater for users of different ages, abilities, and interests, Lines Bros. turned Meccano into a generalist children's construction hobby.[446]

The older Meccano boys' frustrations were further exacerbated by the introduction of new 'Themed Sets' in 1965. In place of the No.1 to No. 10 outfits, the new range had names that corresponded to certain themes, including:

- No. 1: Junior Set
- No. 2: Super Junior Set
- No. 3: Highway Vehicles Set
- No. 4: Airport Service Set
- No. 5: Site Engineering Set
- No. 6: Ocean Terminal Set
- No. 7: Mountain Engineers Set
- No. 8: Breakdown Crew Set
- No. 9: Master Engineer's Set
- No. 10: Oak Cabinet.[447]

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[445] K. D. Brown, 'Death of a Dinosaur: Meccano of Liverpool, 1908-1979,' *Business Archives: Sources and History*, Vol. 66, (1993), pp. 24-29.

[446] G. Byrom, 'What's your problem?' *Meccano Magazine*, Vol. 49, No. 2, (April, 1964), p. 15; and E. Hawkes, *Meccano Magazine*, Vol. VII, No. 3, (March, 1922), p. 1.

[447] The magazine described how the No. 9: Master Engineer's Set contained instructions to build 'London Tower Bridge [and a] robot man.' The models that could be built with these sets bear a striking resemblance to the Meccano sets that are on sale at the time of writing in 2018, which include Meccano: Junior Meccano Engineering and Robotics (which features London Tower Bridge models) and Meccano: Tech (which focuses on building robots).

The instruction manuals that accompanied these sets were also changed, such that they only listed pieces relevant to the theme of the set to which they were attached. This contrasted with previous manuals that had illustrated the full range of Meccano pieces in every set, regardless of the size, making the new Themed Sets were more prescriptive than previous outfits. This meant that users had to buy several manuals to learn about other models, which removed the aspirational element of Meccano that encouraged innovation, creativity, and experimentation with models from larger sets.[448]

The final major change that Lines Bros. made after taking over Meccano Ltd. was the introduction of 'Plastic Meccano' sets in 1965, aimed exclusively at younger children. This change, along with the other new sets, was the final reason given by the Meccanomen for the creation of their 'alternative' version. The plastic Meccano pieces came in 'A,' 'B,' and 'C' sets and were described as 'Safe, Strong, Colourful' (see figure 5.5). As well as being aimed at younger users, Plastic Meccano sets also represented the first time since 1901 that Hornby's standardised Meccano measurements were not followed.[449] This switch from metal to plastic occurred during the same period as an increase in the widespread use of plastic, due to its durability, inexpensiveness, lightweight nature, and versatility.[450]

[448] Patent No. 587-1901, F. Hornby, 'Improvements in Toy or Educational Devices for Children and Young People,' (9 January, 1901).
[449] 'Plastic Meccano,' https://www.meccanoindex.co.uk/Mmanuals/Plastic/index.php?id=1560534545 [accessed 20 June 2018].
[450] S. Freinkel, *Plastics: A Toxic Love Story* (New York, 2011), p. 4.

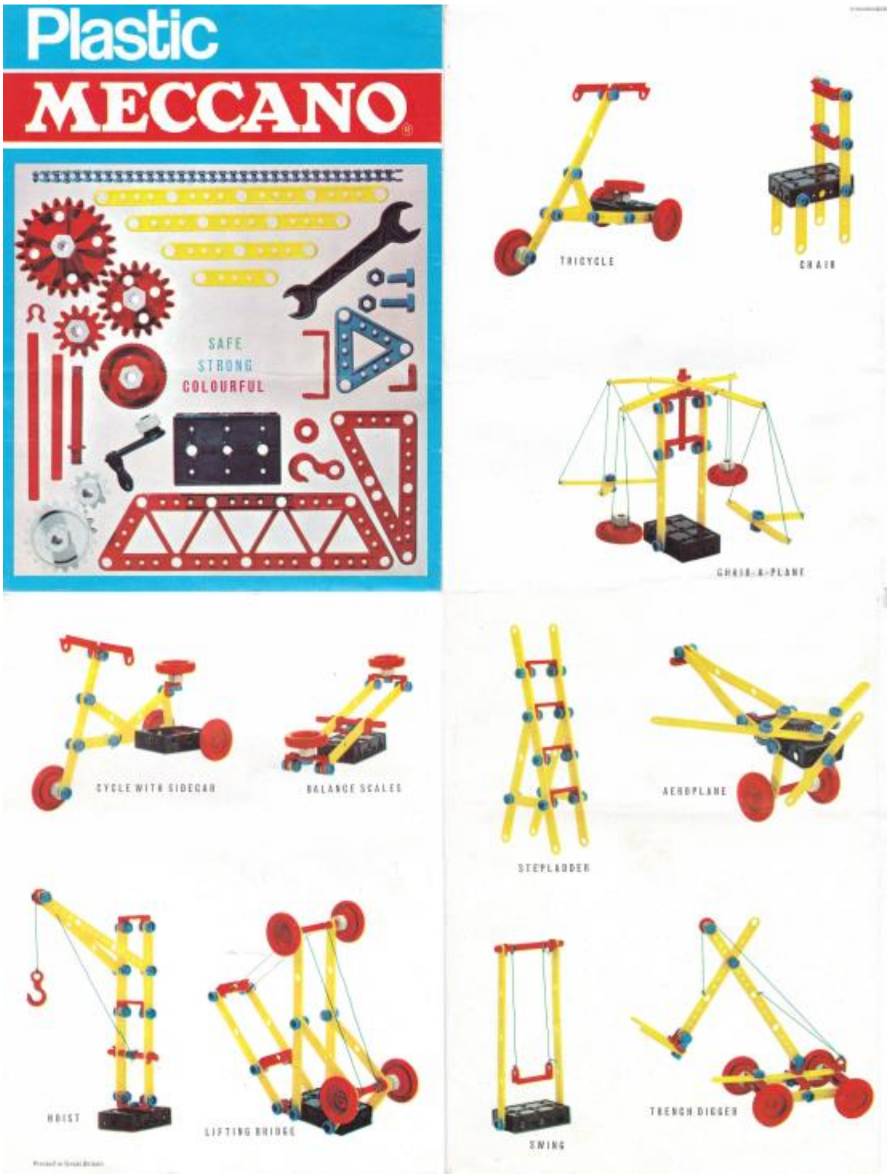


Figure 5.5: An instruction manual for Plastic Meccano, released in 1965 to appeal to younger children. (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/Plastic/index.php?id=1560534545).

The advertisements for all of these sets reverted back to using images of young Meccano boys, and slogans like ‘My dad’s an engineer – so am I!’ (see figure 5.6).[451] While the New Look, Themed, and Plastic Meccano sets increasingly made the ‘mainstream’ version of Meccano into a child’s toy, the new branding would have confirmed to the older users that they were no longer a part of the Meccano ‘brotherhood’ that they had been previously.

[451] C. E. Deane, *Meccano Magazine*, Vol. 50, No. 3, (March, 1965), p. ii; and G. Byrom, ‘Colourful Move by Meccano,’ *Meccano Magazine*, Vol. 49, No. 6, (August, 1964), p. 33.

Figure 5.6: The advert on the left highlights the shift away from Meccano as a hobby for all ages, with the focus on boys emulating their fathers, (Image reproduced from *Meccano Magazine*, Vol. 50. No. 3, (March, 1965), p. 1). The advert on the right for Plastic Meccano demonstrates the increasing focus on boys, with the slogan 'big pieces for little hands,' (alongside possibly the saddest looking boy playing with Meccano that has ever existed). (Image reproduced from *Meccano Magazine*, Vol. 50, No. 12, (December, 1965)).

Meccanoman and popular historian, Roger Marriott discussed these changes in his 2017 article 'The Midlands Meccano Guild Celebrates its 50th Year – A Review' in the *Midlands Meccano Guild Bulletin*. He explained that the child-centred approach of the Plastic Meccano sets did not appeal to the older Meccano boys, who – also frustrated with the New Look sets – continued to use their older red and green Meccano outfits.[452] He stated that the biggest change made by Lines Bros., which precipitated the Meccanomen movement, was their decision to no longer produce the red and green pieces that the older Meccano boys continued to use. The impact of this change is clear in how many of the older Meccano boys sent frustrated letters to the *Meccano Magazine* throughout 1964 and 1965, requesting

[452] R. Marriott, 'The Midlands Meccano Guild Celebrates its 50th Year – A Review' *Midlands Meccano Guild Bulletin*, Issue 70, (October, 2017).

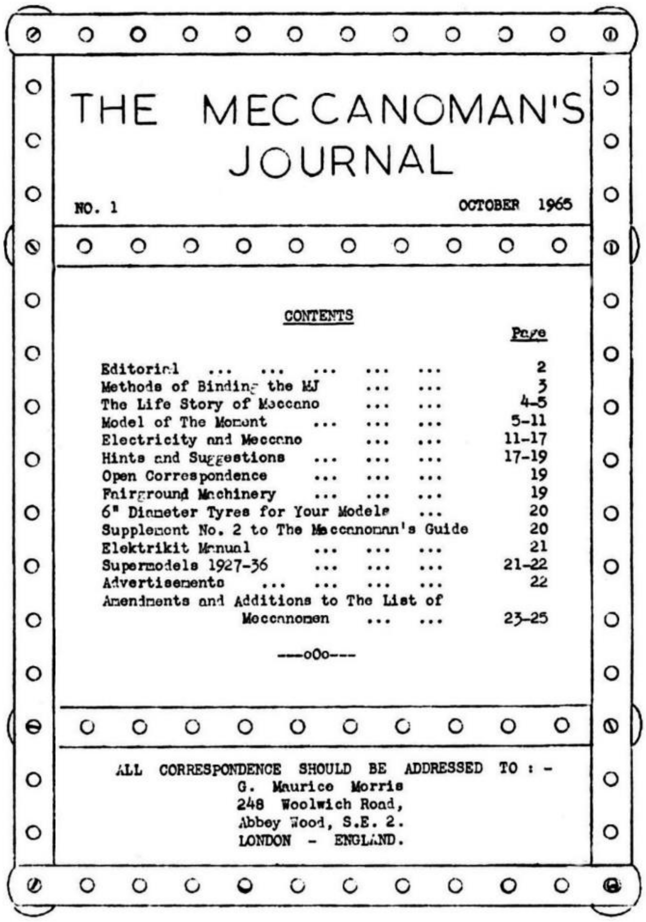
production of older parts and better signposting to existing vendors.[453] While Byrom responded to these requests by increasing the frequency of articles that listed regional dealers, no indication was provided about whether the production of pre-war pieces would be resumed.[454] Figure 5.7 is a map that highlights the geographical spread of the vendors that Byrom published in the magazine, and establishes the limited options to purchase red and green Meccano.

Figure 5.7: This image plots the location of the Meccano vendors in 1965 in red and the location of the Midlands Meccano Guild in green. (Image reproduced from https://www.mapcustomizer.com/ and the locations of vendors reproduced from *Meccano Magazine*s issues).

[453] These letters featured prominently in G. Byrom, 'What's Your Problem?' *Meccano Magazine*, Vol. 49, No. 12, (December, 1964); and G. Byrom, 'What's Your Problem?' *Meccano Magazine*, Vol. 50, No.1, (January, 1965).

[454] An example of these two articles features in J. D. McHard, 'Dealers who stock Meccano spare parts,' *Meccano Magazine*, Vol. 51, No. 5, (May, 1966), pp. 54-55.

In response to the lack of availability, a veteran Meccano hobbyist, G. Maurice Morris created a nationwide postal society called the *Meccanoman's Club* in early 1965.[455] Morris ran the postal society from his home address in London, taking advantage of a large number of local vendors to support the needs of Meccano enthusiasts in more remote locations. His approach meant that the postal society grew to hundreds of subscribers within the first few months, which led him to create the Meccanoman's List; a peer-to-peer mailing list for users to contact each other and request parts of Meccano. The success of these two initiatives led Morris to self-publish the first 'alternative' publication, the *Meccanoman's Journal* in October 1965 (see figure 5.8).



THE MECCANOMAN'S JOURNAL

NO. 1 OCTOBER 1965

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ALL CORRESPONDENCE SHOULD BE ADDRESSED TO : -
G. Maurice Morris
248 Woolwich Road,
Abbey Wood, S.E. 2.
LONDON - ENGLAND.

Figure 5.8: The front cover and contents page of the first *Meccanoman's Journal*. Note the emphasis on Meccano compared to issues of the *Meccano Magazine* from the period. (Image reproduced from the *Meccanoman's Journal*, No. 1, (October, 1965)).

455 J. Gamble, *Midlands Meccano Guild Bulletin*, Issue 44, (December 2010), p. 6.

In contrast to the 'mainstream' version of Meccano that had become almost exclusively designed and marketed as a 'boy's toy,' Morris used the word 'Meccanoman' in the journal to set the interests of the older Meccano boys apart. His publication a more participatory version of the *Meccano Magazine*, providing a platform for users to more actively create an 'alternative' version of Meccano, which they could share amongst themselves and with younger Meccanomen.[456] Morris used his editorial section to remind users to 'Remember that this is **our** Journal and we can put just what we like in it.'[457] The emphasis he placed on the word '**our,**' highlights his intention for the journal to provide a space for members to articulate their concerns against what Stewart has called the 'forced conformity' of the 'mainstream' version of their hobby.[458] One way Morris did this was by introducing an 'Open Correspondence' and 'Hints and Suggestions' section where users could actively request changes to the format, and explain how they had used Meccano in innovative ways.[459] The choice to include the Meccanomen in this way meant that they were actively encouraged to shape the 'golden age' of Meccano that featured in the journal.[460]

Morris also used the publication to encourage readers to become active creators of the 'alternative' version by requesting that they send him their favourite 'obsolete literature,' telling them that '…lucky Meccanomen [must] remember the large majority of less fortunate younger enthusiasts who do not and cannot possess this desirable literature.'[461] His request echoed Hornby's words from the very first *Meccano Magazine* article in 1916, in which he

[456] R. Marriott, *Meccano* (Shire Publications, 2016), p. 24.
[457] G. Maurice Morris, 'Editorial,' *Meccanoman's Journal*, No. 1, (October, 1965), p. 2.
[458] S. Stewart, 'Objects of Desire,' in S. M. Pearce (ed.), *Interpreting Objects and Collections* (Routledge, 2004), p. 255.
[459] G. Maurice Morris, 'Hints and Suggestions' and 'Open Correspondence,' *Meccanoman's Journal*, No. 1, (October, 1965), pp. 17-19.
[460] D. Cavicchi, *Tramps Like Us: Music and Meaning Among Springsteen Fans*, (Oxford University Press, 1998), pp. 18: 136.
[461] G. Maurice Morris, 'Editorial,' *Meccanoman's Journal*, No. 1, (October, 1965), p. 2.

stated, 'Write to the Editor [Hornby] as often as you like; he is just a grown-up boy with a lot of experience, and he knows how boys feel about things, and how to help them out of their difficulties.'[462] Morris's call for these articles told the Meccanomen (many of whom now had families and Meccano boys of their own) that they were now the grown-up boys with a lot of experience, and that to create a version of Meccano for the next generation of Meccano boys, they needed to assume Hornby's role. He also told users in his first editorial that '…although I intended that all material should be fresh and modern, many have requested reprints from obsolete literature, especially such material as "The Life Story of Meccano" and "Electricity Applied to Meccano."'[463] These articles also demonstrate how he used the journal to transport the values of the pre-war version of Meccano into a new space, protecting them against the changes that had been made to 'mainstream' Meccano.[464]

Alongside the creation of the *Meccanoman's Journal*, the closure of the official Meccano Guild in 1965 also inspired a small group of Meccanomen to meet face-to-face. The format of this first meeting laid the groundwork for subsequent Meccanomen groups in the UK. It along with the *Meccanoman's Journal* and the Meccanoman's List were described as the three foundations of the International Society of Meccanomen.[465] The first meeting took place on Sunday 17 October 1965 and has been written about twice in the *Midlands Meccano Guild Bulletin*, the independent publication that the group created. Ernie Chandler wrote in 1972 that he and a few other Meccanomen were invited by Esmond Roden to visit his house in Cheltenham in 1965, where they showed off their newest models and swapped ideas and pieces that they each needed (see figure 5.9).[466] Meeting face-to-face allowed these

[462] F. Hornby, 'Our First Number,' *Meccano Magazine*, Vol. I, No. 1, (Sept-Oct, 1916), p. 1.
[463] G. Maurice Morris, 'Editorial,' *Meccanoman's Journal*, No. 1, (October, 1965), p. 2.
[464] G. Maurice Morris, 'Model of the Moment,' *Meccanoman's Journal*, No. 1, (October, 1965), pp. 5-11.
[465] J. Gamble, *Midlands Meccano Guild Bulletin*, Issue 44, (December, 2010), p. 5.
[466] E. Chandler, *Midlands Meccano Guild Bulletin*, Issue 2, (April, 1978), p. 3.

Meccanomen to actively shape their hobby through the creation of a site of exchange where they could develop certain aspects of the past in relation to what they believed was the 'golden age' of Meccano.[467]

Figure 5.9: An image of the Magnificent Meccano Seven: A meeting at Esmond Roden's home in 1965. Left-right: Bob Faulkner, Esmond Roden, Jack Partridge, David Goodman, Ernie Chandler, Bert Love, and Eric Jenkins. (Image reproduced from *Midlands Meccano Guild Bulletin*, Issue 44, December 2010).

Meccanoman Jim Gamble wrote more about this first meeting in 2010, stating that their popularity, along with the size of the attendees' Meccano models, made it impossible to continue the meetings at Esmond's home, leading Ernie and another Meccanoman, Bert Love, to secure the St. John's Ambulance Hall in Stratford-upon-Avon. Bert and Ernie contacted Morris and collaborated to use the contact details of members of the Meccanoman's List to invite local enthusiasts to the first official meeting of the Meccanomen, held on Saturday 28th October 1967. The meeting ran from 2pm-8pm, beginning with model demonstrations and a break at 4.30pm for afternoon tea before the official business of the meeting was conducted.

[467] N. Gregson, and L. Crewe, *Second Hand Cultures* (Berg, 2003), p. 4.

This official business represented the first active reshaping of the ‘alternative’ version, which began with the election of the officers and a discussion about how to pursue a positive relationship between their pre-war version and the *Meccano Magazine*. The group then discussed a name and settled on the ‘Midlands Meccano Guild,’ which they thought allowed the group to embody the ‘golden age’ values that had been attached to the recently defunct Meccano Guild.[468] This choice of name for their group further demonstrates how they actively shaped aspects of their ‘alternative’ version of Meccano from the past to suit their needs in the present.

However, the most profound way that these Meccanomen reshaped their version of Meccano occurred during their discussions about the requirements of membership. In contrast to the ‘mainstream’ version of Meccano that continued to focus on younger boys, the Meccanomen concluded that there should be no upper or lower age limit, encouraging the sons of the Meccanomen to attend alongside their fathers. They also decided that all the models displayed had to be made from Meccano, instead of the more general interest construction hobbies that had begun to feature heavily in the *Meccano Magazine*. These two decisions – on the age of membership and the types of models that could be displayed at meetings – were the first changes that fundamentally separated the Meccanomen’s ‘alternative’ version from the ‘mainstream’ version of Meccano.

At the same time as the Meccanomen began to redefine aspects of their ‘alternative’ version in these meetings, the *Meccano Magazine* – under the publishers Skinner and Co. Ltd. – was discontinued in July 1967. The reason given in the magazine was that after fifty-one years, ‘economic circumstances’ had made it impossible to continue with the publication.[469]

[468] J. Gamble, *Midlands Meccano Guild Bulletin*, Issue 44, (December 2010), pp. 5-12.
[469] J. D. McHard, ‘Editorial,’ *Meccano Magazine*, Vol. 52, No. 6, (June, 1967), p. 7.

Despite the assumption that this closure would not have been a disappointment to the Meccanomen (due to their frustrations with the changes to the 'mainstream' version) a Meccanoman told me that the magazine was 'still significantly supported by members in the 1960s and 1970s' as it provided them with a means to publicise their 'alternative' version to a wider audience.[470] This continued support was evident in the Meccanomen's celebration of the news that a new iteration of the *Meccano Magazine* was going to be released under a new external publisher – Model Aeronautical Press – in January 1968. To mark the occasion, Betty Love (the wife of Bert), baked a cake for the first meeting on Saturday 28th October 1967 to 'christen' the return of the magazine (see figure 5.10).

Figure 5.10: An image of the original Meccanomen at the 1967 meeting in Stratford-on-Avon 'christening' the new *Meccano Magazine* with a cake baked by Bert Love's wife Betty. These original members (left to right) include: Bill Winter, Clive Hine, Jack Partridge, Alf Hindmarsh, Roger Lloyd, Ron Fail, Esmond Roden, Ernie Chandler, Bob Faulkener, Betty Love, Arthur Locke, Bert Love, Dick Hardyman, Pat Briggs, Dennis Perkins, Dick Hardyman's son, Eric Taylor, Jim Gamble, David Goodman (father of Matt Goodman). (Image reproduced from *Midlands Meccano Guild Bulletin*, Issue 44, December 2010).

The continued link between the two versions of Meccano is apparent as the christening cake – featuring red and green pre-war Meccano pieces – and the activities of the Meccanomen's

[470] Roger Marriott, personal communication, 22 November 2018.

first meeting were included in the first issue of the new iteration of the *Meccano Magazine* (see figure 5.11).

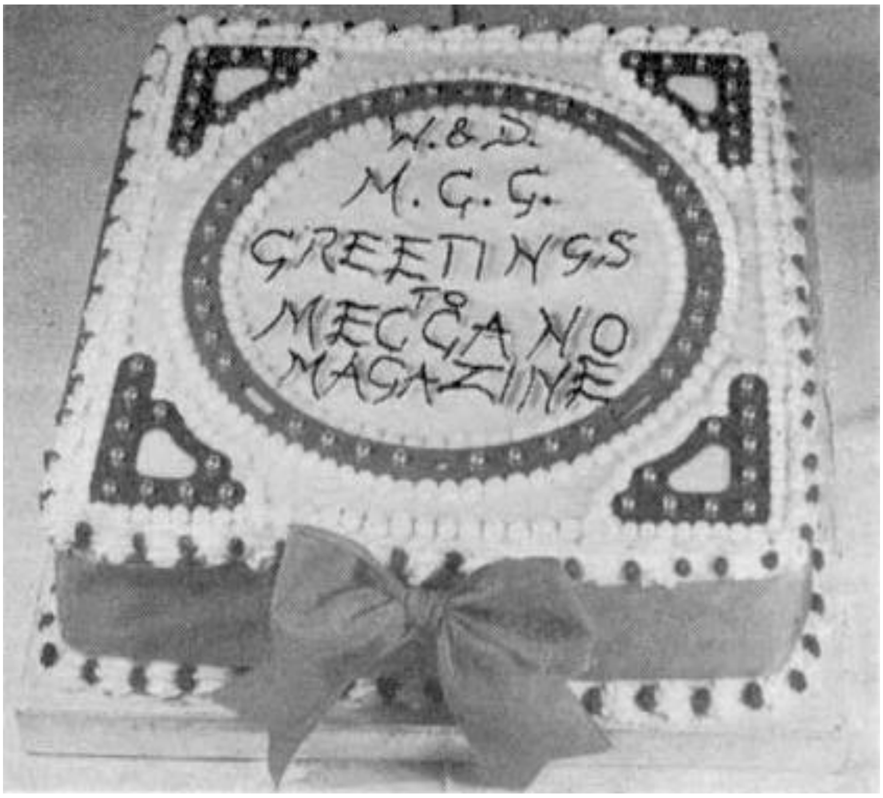

Figure 5.11: An image of the cake created and cut by the Midlands Meccano Guild to 'christen' the return of the *Meccano Magazine*. Note the real Meccano pieces used on the cake. (Image reproduced from *Meccano Magazine*, Vol. 53, No. 1 (January, 1968)).

John Franklin (the editor of the new *Meccano Magazine*), told readers that the Meccanomen's 'programme of model demonstrations, exhibitions of old *Meccano Magazine*s, and a 16mm cine-film of models in action' had been a great success. His editorial also helped to legitimise the Meccanomen's 'alternative' version, stating that the older format of the magazine '…[had] been held in the highest esteem by succeeding generations of users, as much for its informational engineering and creative features, as for its Meccano Model-Building pages.' He also addressed the frustrations the Meccanomen had had with the 'mainstream' version and signalled that Meccano was changing, stating that '…in recent years, after some 51 years of continuity, the *Meccano Magazine* had changed considerably in editorial content and format, and we feel sure that *Meccano Magazine* is now here to stay, with a progressive editorial content and stabilised Meccano format.'[471] Franklin initially tried to cater to the Meccanomen by bringing back some of the signs and symbols of the older *Meccano Magazine* format. These included the return of a Meccano model on the front cover, a variety of Meccano model-building pages, and reprints of two models from the 1920s, which the magazine described as 'Simply Ageless' (see figure 5.12).[472] However, the Meccano model-making content was reduced within a year, and the version of Meccano that featured was once again predominantly aimed at children, with models of a 'Rope-Making Machine' and the 'Fork Lift Truck' made from New Look, and Plastic Meccano sets.[473]

Figure 5.12: The first cover of the reformatted magazine under publishers M.A.P. in January 1968. Note the emphasis on a large, complex Meccano model – pleasing Meccanomen, and the presence of a boy, to continue to attract a newer, younger audience. (Image reproduced from *Meccano Magazine*, Vol. 53, No. 1 (January, 1968)).

[471] J. Franklin, 'Workbench,' *Meccano Magazine*, Vol. 53, No. 1, (January, 1968), p. 9.
[472] J. Franklin, 'Simply Ageless,' *Meccano Magazine*, Vol. 53, No. 1, (January, 1968), pp. 23-24.
[473] D. Rothwell, 'Taylor's Rope-Making Machine,' *Meccano Magazine*, Vol. 54, No. 9, (September, 1969), pp. 438-440; and D. Rothwell, 'Meccano Fork Lift Truck,' *Meccano Magazine*, Vol. 54, No. 10, (October, 1969), pp. 498-499.

The Meccanomen's frustration with these changes was expressed in the corresponding October 1969 issue of the *Meccanoman's Journal*. The editorial – reflecting on a user questionnaire that had been attached to subscription forms to the journal in late 1968 – described how all desired more discussion and instructions for models 'with more complex mechanisms and electrical movements.'[474] In subsequent issues, the *Meccanoman's Journal* published a series of extensive descriptions for more complex models, including a differential mechanism for small-scale motor vehicles, a grab operating device, and a dynamometer for testing motor power.[475] This highlights the changes made to 'mainstream' Meccano in the 1960s by Lines Bros. that led the Meccanomen to develop their own 'alternative' version. It established that the former Meccano boys came to see themselves as Frank Hornby's successors, leading them to try and reinvigorate the version of Meccano that they believed he had developed. However, it also demonstrated that in the process of developing their version, the Meccanomen began to alter aspects of the past by harking back to a 'golden age' of Meccano based on their nostalgia.

[474] G. Maurice Morris, 'Editorial,' *Meccanoman's Journal*, No. 17, (October, 1969), p. 449.
[475] Various models found in *Meccanoman's Journal*, No. 17, (October, 1969), pp. 462; 467-468; and 471-474.

4. A ‘Peaceful Co-existence’: 1971-1981

Meccano Ltd. and Lines Bros. continued to struggle throughout the late 1960s and early 1970s.[476] In an attempt to innovate ‘mainstream’ Meccano, they introduced ‘Pocket Meccano’ sets, which contained smaller pieces of plastic and metal Meccano and were designed to be carried around and built anywhere. The creation of Pocket Meccano, marketed as ‘the start of something big,’ demonstrates how the ‘mainstream’ version of Meccano was still predominantly aimed at younger children (see figure 5.13).[477]

Figure 5.13: The manual released along with the new Pocket Meccano sets. (Image reproduced from https://www.meccanoindex.co.uk/Mmanuals/1970/Covers.php?id=1565446655#nogo%22).

[476] This continued growth and demand for independent publications is discussed in *Meccano Engineer: Incorporating the Junior Meccano Engineer*, No. 7, (March, 1975).
[477] ‘Miscellaneous Meccano Ltd. Leaflets,’ https://www.meccanoindex.co.uk/Cats/Other.php?id=1560535703 [accessed 20 June 2018].

However, despite some initial success with these new sets, further market deregulation in the 1960s and 1970s, along with the increasing popularity of the cheaper plastic alternatives, and the influx of American adverts on British TV (that Meccano Ltd. refused to copy) contributed to the eventual liquidation of Lines Bros. in 1971.

Airfix Industries subsequently purchased Meccano Ltd. and made changes within a year, taking back ownership of the *Meccano Magazine* from the Model Aeronautical Press and returning it to Meccano Ltd. for the first time since 1964.[478] When it was relaunched in April 1973, the monthly magazine was replaced with the *Meccano Magazine Quarterly* to save costs (see figure 5.14).[479] The new editor of the magazine, Chris Jelley, wrote that Airfix had made these changes to try and 'rejuvenate the community,' and that the magazine would '…once again be devoted almost completely to the Meccano hobby and regarded by the company as the hobby's official organ.'[480] The design of this iteration of the magazine was much closer to the text-heavy format of the initial 1916 issues than the more child-friendly covers of later iterations. While there is no feedback on this new front cover from readers, the continued decrease in readership suggests the new format did not rejuvenate the community in the way Jelley had hoped.[481] This explains why, when the magazine was relaunched again in 1977, it was much closer to the design of the magazine from between 1924-1964.

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[478] A. Ward, *The Boy's Book of Airfix: Who Says You Ever Have To Grow Up* (Ebury Press, 2009), p. 73.
[479] This change was first discussed in V. E. Smeed, 'On the Editor's Desk,' *Meccano Magazine*, Vol. 57, No. 12, (December 1972), p. 581.
[480] C. J. Jelley, 'Editorial,' *Meccano Magazine*, Vol. 58, No. 1, (April, 1973), p. 1. Jelley later reflected in 1976 that this change to the quarterly format was beneficial as gave him and his team more time to create and publish each issue, alongside his full-time role as Press and Public Relations Manager at the Meccano Company. He discussed these developments in 'Change for the Better,' *Meccano Magazine*, Vol. 61, No. 4, (October, 1976), p. 93.
[481] K. D. Brown, *Factory of Dreams: A History of Meccano Ltd.,* (Crucible Books, 2007); and K. D. Brown, 'Death of a Dinosaur: Meccano of Liverpool, 1908-1979,' *Business Archives: Sources and History*, Vol. 66, (1993), pp. 27-31.

MECCANO®

Magazine

20p

QUARTERLY

Vol.58 No.1 MECCANO MAGAZINE FOUNDED 1916 April 1973

WELCOME !

"Welcome to the Meccano Magazine Quarterly" is the comment which springs unbidden to mind as I sit down to write – and I do mean welcome! I am delighted that Meccano Limited has decided to go ahead with the magazine and I have no doubt that every MMQ reader without exception echoes this sentiment.

The important thing to remember about the MMQ is that this is now very much the Meccano modellers' magazine. After something like nine years in other hands, it has once again come home to Meccano Limited – published by us and, for the first time, also printed by us. It is devoted almost completely to the Meccano hobby and is regarded by the company as the hobby's official organ. It is, therefore, your magazine and so we will always be pleased to hear from any reader who has anything of a Meccano nature which he feels might be of interest to other readers. We cannot of course guarantee publication, but we promise that everything will be very carefully studied and we will certainly use anything suitable when and if we have the space. In any case, we would like to have your opinion of the magazine, together with any ideas you might have for improving it.

EXTRA PAGES

Most modellers at present reading these words were notified by letter of the forthcoming publication of the MMQ. In the letter, we said that the magazine would have a minimum of 16 pages, including covers, and we fully expected that the first edition would be a 16-pager. Much to our delight, however, we have received such excellent advertising support from specialist Meccano dealers and others with a directly associated interest that we have been able to add an extra eight pages to this issue. They serve as an unexpected bonus, the thanks for which must go entirely to our advertisers and I am sure that, where possible, readers will reciprocate by supporting the advertisers. (Don't forget to say you saw them in the MMQ!).

This brings me to a very important point. The MMQ is regarded by Meccano Limited as a service to Meccano model-builders. As such, it is not required to make a profit for the company, but nor is it expected to make a loss. It is expected only to support itself and for this reason it has been costed on a break-even basis with the subscription rates being set accordingly. By receiving more advertising support than estimated, we raised a small cash surplus, and were able to pass this on to you in the form of extra pages. We will do the same thing at every opportunity, although, of course, it may not be possible to do so in every issue.

Editorial conference! Your Editor, seated, discusses details of the first issue of Meccano Magazine Quarterly with Editorial Director, Mr. J. D. McHard, right, and Assistant Editor Mr. M. K. Peddie.

CONTINUITY

Although this is the first MMQ, you will see from the imprint above that it is officially regarded as issue No. 1 of the 58th volume! The reason for this is that the magazine is not really a new publication, but rather a continuation of the "old" Meccano Magazine. The December 1972 MM was Volume 57, No. 12, therefore this issue is Volume 58, No. 1 – i.e. the first issue of 1973. Thus, continuity is preserved.

Anyway, here we are with the first MMQ. I hope you are happy with it!

The Editor

EDITORIAL DIRECTOR: J.D. McHard
EDITOR: C. J. Jelley
ASSISTANT EDITOR: M. K. Peddie

PUBLISHED FOUR TIMES PER YEAR IN JANUARY, APRIL, JULY AND OCTOBER

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Figure 5.14: The front cover of the first *Meccano Magazine* Quarterly. (Image reproduced from *Meccano Magazine*, Vol. 58, No. 1, (April, 1973)).

Nevertheless, alongside this relaunch of the magazine, Airfix also released 'Meccano Multikits,' which they marketed as 'the greatest single advance in Meccano thinking since the war.'[482] However, they were, in reality, an extension of the Themed Sets concept that Lines Bros. had introduced in 1964, as they contained parts and instructions to build specific models related to distinct themes, rather than general Meccano outfits.[483] During the same period, the Meccanomen continued to develop their 'alternative' version, creating three new clubs,

[482] Various models found in *Meccano Magazine*, Vol. 58, No. 1, (April, 1973), pp. 2-3: 4-6: 7-10: 15-17.

[483] C. J. Jelley, 'Multikits,' *Meccano Magazine*, Vol. 58, No. 1, (April 1973), pp. 13-14; and G. Byrom, 'Colourful Move by Meccano,' *Meccano Magazine*, Vol. 49, No. 6, (August, 1964), pp. 32-33.

including the Holy Trinity Meccano Club, the Henley Society of Meccano Engineers, and the North West Meccano Guild. As with the Meccanomen in the Midlands Meccano Guild, these new clubs began to cater to the needs of their users to satisfy their nostalgia. Despite all using the same pre-war Meccano pieces, the 'golden age' versions of Meccano at these clubs were all becoming differentiated based on the desires and demographics of their users.

In contrast to the Midlands Meccano Guild in 1965, Meccanoman Geoff Wright formed the Henley Society of Meccano Engineers as a meeting space for those who visited his shop (MW Models) to buy pre-war Meccano pieces in 1972.[484] He had initially set up his shop in 1970, and (similar to G. Maurice Morris and the Meccanoman's List) took to sending out regular newsletters (the *MW NewsSheet*) to Meccanomen, which contained extensive lists of second-hand parts, instruction booklets, and outfits.[485] Geoff and other members at the Henley Society used these methods to create the Henley Society of Junior Meccano Engineers, which provided a space where the sons of the Meccanomen could meet to learn more about a version of Meccano that was based on their fathers' nostalgia. The interaction between fathers and their children in learning has been explored in sociological studies, indicating that having a child causes fathers to become reflective about their pasts and the types of lessons they want to teach their children.[486] The society eventually decided to

[484] 'The Henley Society of Meccano Engineers,' http://www.hsme.org.uk/about.html [accessed 10 August 2017].

[485] 'Golden Spanner Award 2007: Geoff Wright,' http://internationalmeccanomen.org.uk/ISM/GSAward/album/2007%20Geoff%20Wright%20%20(United%20Kingdom)/slides/03%20Geoff%20in%20Meccano%20Wonderland.html [accessed 18 August 2017].

[486] D. M. Newman, *Sociology: Exploring the Architecture of Everyday Life* (Pine Forge Press, 2008), pp. 193-195; R. Montemayor, 'Boys as Fathers: Coping with the Dilemmas of Adolescence,' in A. B. Elster, and M. E. Lamb (eds.), *Adolescent Fatherhood* (Taylor Francis, 2009), pp. 1-15: 55-58; and S. Coontz, *The Way We Never Were: American Families and the Nostalgia Trap* (Basic Books, 2000).

integrate the adult and junior Meccano engineers in 1976, in a move that they believed brought the interests of both groups into a single 'golden age' version of Meccano.[487]

The North West Meccano Guild was formed by 'half a dozen youthful enthusiasts from Lancashire,' who met to form a group for the exchange of ideas and help in 1973.[488] Meccanoman Richard Watson's view of the club in 2018 was that while 'the average age of the membership has risen somewhat,' the members of the guild still meet regularly to 'share their ideas and enthusiasm.'[489] These younger members of the North West Meccano Guild and Henley Society of Junior Meccano Engineers are now the contemporary Meccanomen, who Chapter Six demonstrates compose perspectives of their hobby that are based on their personal experiences rather than a nostalgia for a past that they did not live through. Their examples hint at how aspects of the 'golden age' 'alternative' version of Meccano have been changed to reflect the broader passions of Meccanomen in each club, rather than the conventional public history of Meccano.

Each of these Meccanomen clubs published their own independent newsletters that borrowed elements from the *Meccanoman's Journal* and changed them to meet the expectations and desires of their members.[490] Mike Nicholls edited the Henley Society of Meccano Engineers' publication (the *Junior Meccano Engineer*) from 1973 to 1976, publishing it through M. W. Publications (later Delta Graphics).[491] Nicholls later explained that the [*Junior*] *Meccano Engineer* had 'not [been] in competition with our friends at *MMQ*; we offer

[487] 'The Henley Society of Meccano Engineers,' http://www.hsme.org.uk/about.html [accessed 10 August 2017].
[488] 'North West Meccano Guild,' http://www.northwestmeccano.co.uk/index.html [accessed 10 August 2017].
[489] 'North West Meccano Guild,' http://www.northwestmeccano.co.uk/index.html [accessed 10 August 2017].
[490] Analysing the 'golden ages' of each publication in greater depth is too large a project for this chapter, but represents an interesting avenue for future research.
[491] *Junior Meccano Engineer*, No.1, (September, 1973), pp. 1-4. The publication dropped 'Junior' within a few issues.

an alternative reading in a different style, as our regular readers will already know.'[492] The success of Nicholls' publication led Airfix to hire him as the new editor of the *Meccano Magazine Quarterly* in 1976, in an attempt to increase the popularity of 'mainstream' Meccano. He replaced the previous editor Chris Jelley, who told readers that Nicholls would step down as editor of the *Meccano Engineer* and incorporate aspects of the 'alternative' version of Meccano and the independent publications into a new iteration of the *Meccano Magazine*. Jelley explained that despite his best efforts since 1973, '[the] magazine's limitations' had continued, due to the lack of 'facilities to improve things.' In contrast, he pointed to the admired growth of the independently-published *Meccano Engineer*, which be believed was 'distinctly superior to the *MMQ*.'[493] This transfer of the magazine from Binns Road to Delta Graphics represented the moment that the Meccanomen had the opportunity to use the 'official organ' of 'mainstream' Meccano to publish their 'alternative' version of Meccano, based around their nostalgia for a 'golden age' of the toy.

The decision to recruit Nicholls to replace Jelley highlighted Airfix's desire to bring the Meccanomen back to the 'mainstream' version. Nicholls stated in his first issue that he was looking forward to a 'peaceful co-existence' between the two versions of Meccano and their publications. He explained to readers that the new version would be 'primarily a *Meccano Magazine*' with which both '*MMQ* and *ME* [*Meccano Engineer*] readers alike will feel at home.' He outlined his vision to '…get the *MM* back on the bookstalls and…expand its readership…in our campaign to reinstate the *MM* to its former place as an important international journal.'[494] The first step that Nicholls took towards achieving this unification of

[492] M. Nicholls, 'Something for Everyone,' *Meccano Engineer: Incorporating the Junior Meccano Engineer*, No. 7, (March, 1975), p. 107.
[493] C. J. Jelley, 'Change for the Better,' *Meccano Magazine* Vol. 61, No. 4, (October, 1976), p. 93.
[494] M. Nicholls, 'Look At The Future,' *Meccano Magazine*, Vol. 61, No. 4, (October, 1976), p. 95.

the two versions was the reintroduction of the pre-1964 title font and full-colour Meccano images on the front cover, along with the tagline 'Incorporating *Meccano Engineer* & *Meccanoman's Journal*' (see figure 5.15).[495]

Figure 5.15: These two covers, from 1935 and 1977, share a number of similarities, in terms of both font and style. (Images from *Meccano Magazine*, Vol XX, No. 7, (July 1935); and *Meccano Magazine*, Vol 62, No. 2, (April, 1977)).

The new format also increased the number of pre-war Meccano modelling articles and incorporated the 'Postbag' section from the *Meccano Engineer*. Nicholls further added three full pages of members' correspondence and ideas, realising the desire that Morris had expressed in issue one of the *Meccanoman's Journal*: 'Remember that this is **our** Journal.'[496] The spaces given to reporting the activities of the Meccano clubs were also quadrupled in length from the previous format.[497] Nicholls' issues also removed the advertisements for all

[495] M. Nicholls, 'Editorial,' *Meccano Magazine*, Vol. 62, No. 1, (January, 1977).
[496] G. Maurice Morris, 'Editorial,' *Meccanoman's Journal*, No. 1, (October, 1965), p. 2.
[497] M. Nicholls, 'Darlington Review,' *Meccano Magazine*, Vol. 62, No. 1, (January, 1977), pp. 12-13; and 'Club Notes,' *Meccano Magazine*, Vol. 62, No. 1, (January, 1977), pp. 28-29.

non-Meccano related items and replaced them with more member-focused materials that were directly related to a specific Meccano model.[498]

It was in Nicholls' first issue that the phrase 'golden age' was printed in a 'mainstream' Meccano publication for the first time. It featured in an article written by Meccanoman Michael Walker, who used the phrase when comparing the differences between the 'mainstream' Meccano Guild (that existed from 1919 to 1965) and the 'alternative' groups such as the Midlands Meccano Guild that had developed since. He asserted that the community was 'fast approaching a similar situation to the pre-war 'Golden Age' of Meccano,' citing 'the resurgent *Meccano Magazine* is further proof of this, pre-war type cover to boot.' His words suggest that he believed the 'alternative' 'golden age' version had superseded the 'mainstream' version of Meccano. He called for the return of the pre-war membership badges for a 're-vamped Meccano Guild or federation of existing Meccano Clubs [to] give a worldwide sense of unity to the hobby.'[499] However, he, like previous Meccanomen, also changed an aspect of the 'golden age' in this article, based on his personal nostalgia. This was evident in how his call for the guild to be reinstated overlooked the fact that the original Meccano Guild and these membership badges had been in existence for 46 years, both before and after the Second World War, and not just the pre-war, 'golden age' period to which he desired to return. This is an example of how the Meccanomen changed aspects of their 'golden age' nostalgia to service their desires for their hobby in the present. Nevertheless, despite being published in 'mainstream' *Meccano Magazine*, Walker's call for a revamped guild that used pre-war badges was not met by Meccano Ltd.

[498] M. J. Walker, 'North-West Frontier,' *Meccano Magazine*, Vol. 62, No. 1, (January, 1977), p. 43; M. Nicholls, 'Exhibition Announcements,' *Meccano Magazine*, Vol. 62, No. 1, (January, 1977), p. 44; and 'Classified Advertisements,' *Meccano Magazine*, Vol. 62, No. 1, (January, 1977), p. 45.
[499] M. J. Walker, 'Join the Meccano Guild,' *Meccano Magazine*, Vol. 62, No. 2, (April, 1977), p. 93.

Despite Nicholls' assertion that there would be a 'peaceful co-existence' between the two versions, he was replaced by the previous editor Chris Jelley after just two issues. Although the reasons for this change were never publicly disclosed in the magazine, the fact that Meccano Ltd. no longer made or sold pieces from the 'golden age' period of Meccano meant that when Airfix released new sets in 1978, they were in direct competition with Nicholls' models made from 'golden age' (and discontinued) pre-war red and green pieces and outfits. The disparity between the two versions is visible in Nicholls' second issue. It presented stories of pre-war pieces alongside a 'Special 8-Page Supplement on Today's Meccano,' which contained adverts for the 'mainstream' Meccano that the Meccanomen had organised themselves against since 1965.[500] It is somewhat surprising that Airfix did not realise the problematic contrast between their version of Meccano and the Meccanomen's 'alternative' version before these issues were published.[501]

In response to the sudden change of editorship, many Meccanomen wrote to the magazine in Jelley's April 1978 issue to complain. One of these Meccanomen was J. Horsman, who wrote that the reversion to non-Meccano articles would not find 'general approval among your readers.' Horsman asserted that '*MM* is essentially a specialist publication' and that its readers did not want to read about the 'Concorde or space exploration.'[502] However, Horsman's desire for a return to 'specialist publication' from the pre-war 'golden age' contrasted to the realities of the version of Meccano that Hawks developed before the Second World War. Under Hawks, the *Meccano Magazine* had been a broader publication that had contained stories of adventurers and explorations. Despite this, the magazine received many

[500] M. Peddie, 'Special 8-Page Supplement on Today's Meccano,' in *Meccano Magazine*, Vol. 62, No. 2, (April, 1977), pp. 71-78.
[501] Despite extensively searching the archives for more information on Airfix's decision, I could not find out why they did not realise this contrast was problematic sooner.
[502] J. D. Horsman letter to M. Nicholls, 'Postbag,' *Meccano Magazine*, Vol. 63, No. 2, (April, 1978), p. 68.

letters similar to Horsman's in subsequent issues, demonstrating that the Meccanomen had amended certain aspects of the 'golden age' to meet their nostalgia and desires, and to escape into what David Lowenthal has called 'fantasies about the past.'[503]

While a growing number of users engaged with the 'alternative' version of Meccano, Airfix Industries – plagued by increasing debt and crumbling infrastructure at the Binns Road factory – closed the doors for the final time on 30 November 1979.[504] The company entered administration in 1981, with the final publication of the *Meccano Magazine* coming in April of the same year. This brought 65 relatively unbroken years of the magazine and 80 years of 'mainstream' Meccano to an end.

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[503] D. Lowenthal, *The Past Is A Foreign Country – Revisited* (Cambridge University Press, 2015), p. 8.
[504] R. Marriott, *Meccano* (Shire Publications, 2016), p. 52; and A. Ward, *The Boy's Book of Airfix: Who Says You Ever Have To Grow Up* (Ebury Press, 2009), p. 78.

5. Reflexive Nostalgia and Diverging Versions: 1981-2018

The Meccanomen formed many new groups and publications after the collapse of 'mainstream' Meccano, primarily as 'spaces for users to share ideas and their spare parts.'[505] These included the North Eastern Meccano Society in 1975; the South East London Meccano Club in 1976; the Solent Meccano Club in 1976; and the West London Meccano Society in 1978, which was designed to serve 'as a reminder of youthful exploits with spanner and screwdriver.'[506] The success of the 'alternative' version of Meccano continued into the 1980s, with the formation of the Sheffield Meccano Guild in 1981, the Meccano Society of Scotland in 1984, the South West Meccano Club in 1984, the Runnymede Meccano Society in 1986, and the Telford and Ironbridge Meccano Society in 1991. These new groups all created their own newsletters and publications, dedicated to 'alternative' versions of Meccano that reflected their members' nostalgia. This section will demonstrate that as the second generation replaced the older Meccanomen, they began to change the 'alternative' version of Meccano to reflect their specific and personal experiences, rather than nostalgia for a 'golden age.'

As the number of 'alternative' groups and publications grew in the UK and around the world, requests for an umbrella organisation to coordinate them also increased. This request was initially answered by Meccanoman John Westwood, who created the *International Meccanoman* journal in 1988. The *International Meccanoman* borrowed a series of elements from the *Meccanoman's Journal*, the *Meccano Engineer*, and represented the first attempt to bring the different groups of Meccanomen together since the Meccano Guild in 1919. In

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[505] C. J. Jelley, 'Specialist Directory,' *Meccano Magazine*, Vol. 64, No. 1, (January 1979), pp. 37-38.

[506] The North Eastern Meccano Society,' http://www.nems.club/about.html [accessed 10 August 2017]; 'The South East London Meccano Club,' https://www.selmec.org.uk/about.aspx [accessed 10 August 2017]; 'The Solent Meccano Club,' https://sites.google.com/site/thesolentmeccanoclub/history [accessed 10 August 2017]; and 'West London Meccano Society,' http://www.hsomerville.com/wlms/ [accessed 10 August 2017].

contrast to the different 'golden age' versions of Meccano that the clubs and their members had previously developed, the *International Meccanoman* presented a specific 'alternative' version of Meccano, which it described as 'Liverpool Meccano.' The *International Meccanoman* established the credentials of 'Liverpool Meccano' by telling readers that as the 'enormous Meccano Ltd. drifted gradually downhill,' the Meccanomen 'by supreme irony' created an 'alternative' version that did not 'depart from the basic constructional principles laid down by Hornby himself.'[507] However, as with the previous versions of the 'golden age' of Meccano, the *International Meccanoman* amended aspects of the past to create 'Liverpool Meccano.' The most obvious element that they amended was the name itself, which was a reference to the Meccano that they believed Hornby had developed at Binns Road.

The *International Meccanoman* also referenced the development of Themed Sets, Plastic Meccano sets, and Pocket Meccano in the 1960s and 1970s as part of this downhill-drift, implying that these had all strayed from the Meccano that they believed Hornby had designed in 1901. The journal stated that in contrast to the 'mainstream' developments, 'Liverpool Meccano' was something 'Hornby would have wanted.[508] However, as Chapter One demonstrated, there was not a single version of Meccano that existed during Hornby's tenure to support this claim; he developed Meccano from an educational toy to a training tool for would-be engineers before Hawks changed it again. Therefore, it is ironic that in describing their vision of Meccano as something that 'Hornby would have wanted,' the 'golden age' version that the *International Meccanoman* cultivated actually departed from the realities of the three versions of Meccano described in Chapter One. This contrast is another example of

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[507] *International Meccanoman*, No. 1, (1988), p. 1.
[508] J. Westwood, 'Editorial,' *International Meccanoman*, No. 1, (1988), p. 2.

how the members of the umbrella organisation actively changed aspects of the past for their 'alternative' version.

Within a year of the development of the *International Meccanoman*, another Meccanoman – Michael Adler – created the International Society of Meccanomen. He worked with John Westwood and incorporated the *International Meccanoman* as the International Society of Meccanomen's primary publication. The vision of this new organisation went beyond the national Meccano Guild that Michael Walker had called for a decade earlier, as it included Meccanomen clubs had been set up many countries around the world, including Argentina (6), Australia (4), Canada (3), New Zealand (5), Israel (1), Malta (1), and Spain (4).[509] The primary goal of the International Society of Meccanomen was to '…unite all Meccanomen in a common brotherhood, which has as its aim the enjoyment of the Meccano system in all its manifestations, be it model building, memorabilia, and historical matter, the collection of Meccano, or the encouragement of special interest groups.'[510] Alongside the focus on the 'memorabilia, and historical matter' the society's logo also reflected the Meccanomen's pre-war 'golden age' version of Meccano and answered Michael Walker's call for a return to the triangle logo of the original Meccano Guild (see figure 5.16).

Figure 5.16: The image on the left is the original logo for the Meccano Guild that featured in the April 1977 issue of the *Meccano Magazine*. (Image reproduced from *Meccano Magazine*, Vol. 62, No. 2, (April, 1977). The image on the right is the logo adopted by the International Society of Meccanomen in 1989. (Image reproduced from http://internationalmeccanomen.org.uk/).

[509] List of International Clubs and Societies, http://internationalmeccanomen.org.uk/ISM/Societys/soc.html [accessed 21 March 2016].
[510] 'The I.S.M.,' http://internationalmeccanomen.org.uk/ISM/1Aims/ISMaims.html [accessed 16 August 2017].

The International Society of Meccanomen is still in existence today with over 600 members in the UK and thousands around the world. For a yearly subscription rate of £25, current members receive quarterly issues of the *International Meccanoman* and access to the International Society of Meccanomen website. This contains forums, subject indexes, worldwide lists of suppliers (just under 500), as well as information about how to join and access the various Meccano groups (just under 1,000 listed).[511] The *International Meccanoman* was expanded in 1992 to three issues per year and published its 84th issue in August 2018; it continues to feature discussions and instructions of pre-war models. However, it also now includes international interest articles, including 'The Gisclard Bridge (If you don't understand it…try to make it in Meccano),' 'My Favourite Meccano Model of All Times,' the 'Sydney Meccano Modellers' Association,' and 'Skegness 2018,' an article that described the yearly gathering of national and international Meccanomen.[512] The irony of this current format of the *International Meccanoman* is that despite their claim that their version of Meccano is something that 'Hornby would have wanted,' their version of Meccano is much closer to Hawks' aspirational emblem of fan-participation in international science and engineering.

An interview with Matt Goodman in April 2016 provided a clear demonstration of how the contemporary Meccanomen have amended Meccano. Goodman was the current Chairman of the West London Meccano Society at the time, as well as the son of one of the original Meccanomen, David Goodman (present at Esmond Roden's house in 1965, see figure 5.9). The interview was relatively informal but has been split into two parts for the sake of analysis in this and the following chapter. Matt's reflections on Meccano in this chapter are

[511] 'Suppliers,' http://ism.alpinered.co.uk/?p=Suppliers [accessed 18 August 2017]; 'Clubs, Societies, & Guilds,' http://ism.alpinered.co.uk/?p=Clubs [accessed 18 August 2017].
[512] *International Meccanoman*, No. 84, (2018).

part of his oral history of Meccano, while his perspectives analysed in Chapter Six are part of what that chapter describes as his ‘participant historiography,’ which provides a critique of the conventional public history and ‘golden age’ of Meccano.

The initial question that I asked Goodman was for him to tell me if Meccano has relevance in today’s society. He replied that:

> [Meccano] is exquisitely efficient…the parts are almost like a well-written computer language [as] Hornby intended real Engineers to use the stuff. And they do. And mathematicians, artists, architects, military designers, astronomers, physicists, biologists, chemists.[513]

While his mention of Hornby implies a ‘golden age,’ his analogy of a Meccano as a ‘computer language’ demonstrates how he has amended his reflections of the past to better reflect his own experiences and career as a computer programmer. Goodman’s perspective on Meccano leads back to the reconsideration of Kroto’s from Chapter One.[514] Through comparing them, it is apparent that both are composed of their personal experiences with Meccano, with Goodman’s assertion that Meccano is similar to a computer language being an equivalent to Kroto’s belief that Meccano helped him learn about atomic structure.

Since transferring to Meccano France, the ‘mainstream’ version of Meccano has also been updated and changed through the introduction of coding, computing, and other aspects

[513] Matt Goodman, personal interview, 10 April 2016.

[514] Kroto’s interview in which he discussed the ‘demise of British engineering’ was on a BBC Radio 4 episode of *Desert Island Discs,* https://www.bbc.co.uk/programmes/p00948nr [accessed 4 July 2016].

of robotics into new products. The three ranges available today are Meccano: Tech, Meccano: Engineering and Robotics, and Meccano: Junior (see figure 5.17).[515]

Figure 5.17: The three main product lines on the Meccano website. (Image reproduced from 'Products,' http://www.meccano.com/products).

Meccano: Tech is comprised of sets that facilitate the construction of Meccanoids that can be programmed by the user and linked to their latest smart devices, using voice recognition and motion capture technology.[516] 'Meccano: Engineering and Robotics' offers both specific model sets – including the Eiffel Tower, Empire State Building, and Ferrari F12 – and general modelling sets that can be used to make up to 25 different motorised models.[517] The third strand – 'Meccano: Junior' – offers pieces that can be turned into a small number of models, introducing children to the 'Mechanical wonders of the world as they bring construction models to life with the Meccano Junior Easy Toolbox set.'[518] The website explains that the main aim of these 'mainstream' sets is to introduce users to 'STEM concepts.'

[515] 'Products,' http://www.meccano.com/products [accessed 12 January 2018].

[516] 'Meccano: Tech,' http://www.meccano.com/product/p10945/meccanoid-g15ks-personal-robot [accessed 12 January 2018].

[517] 'Meccano: Engineering and Robotics,' http://www.meccano.com/product/p10941/eiffel-tower-2-in-1-model-set [accessed 12 January 2018].

[518] 'Meccano: Junior,' http://www.meccano.com/product/p10948/meccano-junior---3-model-set,-mighty-cycles [accessed 12 January 2018].

6. Conclusion

Reflecting on the two versions of Meccano that exist today presents an interesting counterfactual question: which of the two would Frank Hornby want today if he were alive today? Counterfactual histories have often been derided as little better than entertainment due to their tendency to be 'imagined impossible alternatives,' which are disconnected from reality and based on the desire of the historians to tell a particular story.[519] However, the limited question asked in this chapter is not designed to present an impossible alternative history. Instead, I have asked it to allow us to compare the 'golden age' version of Meccano with the product that Hornby developed before the Second World War.[520] It tests the Meccanomen's assertion that their 'alternative' 'golden age' version of Meccano was what 'Hornby would have wanted' against the reality of Hornby's own career and development of Meccano as discussed in Chapter One. Instead of provoking discussions about the historical development of technology (as in previously critiqued counterfactual studies), it helps to illuminate our understanding of the differences and similarities between Hornby's and the Meccanomen's versions.[521]

After creating the toy in 1901, Hornby spent the rest of his life inventing, innovating, and developing Meccano and other products, growing the first Mechanics Made Easy sets from seventeen distinct pieces to outfits containing several hundred in the 1920s.[522] Hornby

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[519] G. Radick, 'Why, What If?,' *Isis*, Vol. 99, (2008), p. 550.

[520] I. Hesketh, 'Counterfactuals and History: Contingency and Convergence in Histories of Science and Life,' *Studies in History and Philosophy of Biological and Biomedical Sciences*, Vol. 58, (2016), p. 44.

[521] For more examples of counterfactual history, refer to G. Radick, 'Other Histories, Other Biologies,' in A. O'Hear (ed.), *Philosophy, Biology, and Life* (Cambridge University Press, 2005), pp. 21-47; G. Radick, 'Why, What If?,' *Isis*, Vol. 99, (2008), pp. 547-551; J. Mokyr, 'King Kong and Cold Fusion: Counterfactual Analysis and the History of Technology,' in P. E. Tetlock, R. N. Lebow, and G. Parker (eds.), *Unmaking the West: "What-If?" Scenarios that Rewrite World History* (The University of Ann Arbor Press, 2006), pp. 277-322; and P. Bowler, *Darwin Deleted: Imagining a World without Darwin* (University of Chicago Press, 2013).

[522] M. P. Gould, *Frank Hornby: The Boy Who Made $1,000,000 with a Toy*, (Fredonia Books, 2004), Ch. 5.

also created and edited the *Meccano Magazine* in 1916 to regulate how the Meccano boys understood the two different versions of the toy that he cultivated. He developed the first version to reflect Samuel Smiles' self-help principles and answer the 'boy problem;' and the second version was a training tool for would-be engineers, designed to appeal to older users. The challenge of getting boys and girls to study Science, Technology, Engineering, and Mathematics (STEM) subjects at school and university is prevalent in Britain today. The Royal Academy of Engineering has described it as a '…well-documented engineering skills crisis [where] an ageing workforce means that hundreds of thousands of skilled technician and professional engineering roles will need replacing over the next ten years.'[523]

The 'mainstream' Meccano ranges today share more of the same principles as Hornby's two pre-war versions of Meccano (as an educational toy for children (Meccano: Junior) and a training tool for would-be engineers (Meccano: Tech and Meccano: Engineering and Robots)) than the Meccanomen's 'alternative' version, which they believe is something 'Hornby would have wanted.'[524] Their aim to teach STEM concepts is reminiscent of Hornby's desire for 'Mechanics Made Easy' to help young boys learn 'mechanical principles.' Therefore, this suggests that if he were alive today, it may be the case that he would have preferred the teaching of STEM principles of the 'mainstream' version, rather than the backward-looking nostalgia of the 'alternative' version.

This chapter has explored the changing versions of Meccano since the Second World War, demonstrating that a failure to innovate was what ultimately led the Meccanomen to develop their 'alternative' version of Meccano in 1965. It demonstrated that their 'alternative' version – which was initially built around a nostalgic desire to return to what they believed to

[523] The Royal Academy of Engineering, 'The UK STEM Education Landscape,' https://www.raeng.org.uk/publications/reports/uk-stem-education-landscape [accessed 20 November 2018].
[524] J. Westwood, 'Editorial,' *International Meccanoman*, No. 1, (1988), p. 2.

be the ‘golden age’ of Meccano situated before the Second World War – helped to inform the conventional public history of Meccano. It also established that the ‘alternative’ version was changed by its own reflexivity, as newer members replaced the original generation of Meccanomen, which meant references to nostalgia for a ‘golden age’ became less prominent. It used the perspective of a contemporary Meccanoman, Matt Goodman to indicate that in contrast to the stated aims of the International Society of Meccanomen, the ‘golden age’ aspects of the conventional public history of Meccano have been further changed by the second generation of Meccanomen in their individual clubs. Chapter Six explores this contrast further through analysing a series of interviews with contemporary Meccanomen and enthusiasts, where they were asked to compose both historical and historiographical perspectives on their hobby. It demonstrates that their co-curated participant historiographies broadly critique the conventional public history of Meccano, and are informed by their personal histories, rather than a ‘golden age’ of the hobby.[525]

[525] L. Jordanova, *History in Practice* (London, 2000); and L. Jordanova, ‘Public History,’ *History Today*, Vol. 50 (5), (2000).

Chapter Six – The Public History of the Meccanomen: Perspectives on the 'Golden Ages' and British Decline

1. Introduction

While three decades have passed since it was initially created, the constitution of the International Society of Meccanomen still contains many references to returning to a 'golden age' of Meccano. The organisation's website references Hornby's original patent with the phrase 'the study and development of Model Engineering through the medium of the Meccano system,' and features the modern, colourised version of the original Meccano Guild logo (see figure 5.16). Alongside these, the 'Aims' statement of the society also features prominent phrases from the conventional public history of Meccano:

> The aim is to unite all Meccanomen in a common brotherhood, which has as its aim the enjoyment of the Meccano system in all its manifestations, be it model building, memorabilia, and historical matter, the collection of Meccano, or the encouragement of special interest groups.[526]

The term 'brotherhood' was used in the earliest issues of the *Meccano Magazine* by a Meccano boy, with Hornby replying 'We could not have expressed it better ourselves.'[527] It also featured in the first issues of the *Meccanoman's Journal* in 1965 as an indication of what the 'alternative' version of Meccano was supposed to represent for the discontented Meccanomen.[528] The continued use of this type of language and signifiers, which places Meccano as 'memorabilia, and historical matter' suggests that the Meccanomen's hobby is

[526] 'Aims,' http://internationalmeccanomen.org.uk/ISM/1Aims/ISMaims.html [accessed 16 August 2017].
[527] J. B. H. Barnard Castle to F. Hornby, 'Our Mail Bag,' *Meccano Magazine*, Vol. I, No. 3, (March, 1917), p. 4.
[528] G. Maurice Morris, 'Editorial,' *Meccanoman's Journal*, No. 1, (October, 1965), p. 2.

still largely dictated by the conventional public history of Meccano. As the International Society of Meccanomen is an umbrella organisation of all official 'alternative' Meccanomen clubs, it therefore follows that the individual clubs would reflect these aims. Despite this, the Meccano Society of Scotland's constitution has the broader aim of 'foster[ing] interest in the Meccano system,' rather than looking back at the 'golden age' of the hobby.[529] This suggests that the individual Meccanomen have broadly moved away from the conventional public history of Meccano.

To test this, I asked Matt Goodman to tell me more about the state of the Meccano clubs today in the second part of our interview, pushing him to reflect on whether the hobby was growing or declining and if clubs were still focused on returning to the 'golden age' of Meccano before the Second World War. I expected Matt to reflect on the past and give me an answer that fits with the conventional public history of Meccano of the International Society of Meccanomen, such as that the hobby was broadly growing and that with over 600 members nationwide and is still a popular pastime. However, he instead suggested that the individual Meccanomen do not see their hobby in the 'golden age' terms I had described. When I subsequently cited Kroto's *Desert Island Discs* interview, the constitution of the International Society of Meccanomen, and the conventional public history of Meccano in academic sources, Goodman critiqued the way these histories of the movement and Meccano had been written, stating that they 'grossly misrepresented and misunderstood the 'golden age.' He told me that all the academic and popular histories of Meccano that he had read, framed the present state of the hobby as 'nothing more than a facsimile of the 'golden ages' of the past.' This was, he said, despite the fact that the movement had 'broadly moved away

[529] 'Meccano Society of Scotland,' http://internationalmeccanomen.org.uk/ism/societys/soc.html [accessed 10 August 2018].

from the nostalgia for the past that many, including [himself], had not lived through.'[530] When reflecting on our interview afterwards, I realised that while Goodman had given me his view of the history of Meccano in the first part of our conversation (in Chapter Five), he had given me his historiographical perspective of the conventional public history of Meccano that historians have previously written in the second part discussed here. While the first part represented traditional oral history practice, whereby participants are asked for their reflections on the past, I was initially unsure how to classify the second part, eventually deciding on the term 'participant historiography.'

While I had always planned to interview the Meccanomen from the outset of this thesis, the original aim had been to collect their oral histories, analyse them for accuracy of recall, and categorise them into separate groups. However, Goodman's 'participant historiography' made me reconsider this aim. Instead of simply testing them for their recall, I wondered if I could work with the other contemporary Meccanomen to co-curate similar historiographical perspectives, which also did not fit with the conventional public history of Meccano that continues to govern their hobby. The initial problem with this idea was that it represented a radical participatory manoeuvre, as the traditional oral history approach tends to separate interviewees from the historiography that is derived from their reflections on the past. Therefore, what follows is a short description of the development of oral history methodology, before a discussion of how I worked to combine principles of both oral history and public history methods to create a space where the Meccanomen and I could work together to co-curate participant historiographies.

[530] Matt Goodman, personal interview, 10 April 2016.

Paul Thompson's *The Voice of the Past: Oral History* (1978) explains how oral history, used well, can help to transform our understanding of the past by breaking down barriers between generations, and also remove the process of writing history, which has its own flaws. These flaws include the preoccupation in much historical literature towards the story of the elites, or of organisations, rather than focusing on the 'everyman' of history.[531] Ken Worpole also reflected on the value of the 'history from below' approach that oral history offered, and asserted that 'History looks different, is different from different points of view, different locations, different class positions…A sense of time, place, and connection is revolutionary.'[532] Other early proponents of oral history viewed it akin to a historical document found in archival sources and attempted to judge it against the same measures of objectivity and subjectivity. This initial 'documentary' approach to oral history as a historical document resulted in the perspectives of participants being judged as unreliable, fallible, and prone to superficiality, gossip, subjectivity, and an oversimplification of past events.[533] However, historians eventually began to change how they approached and used oral history, leading to the 'theoretical turn.'

The theoretical turn in oral history meant that interviews were no longer understood as traditional historical documents plagued by subjectivity, but as texts whose value was in how they reflected the subjectivities of the participant and their intersubjectivities in relation to the historian on a given topic. The idea of intersubjectivity relates to the way that a

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531 P. Thompson, *The Voice of the Past: Oral History* (Oxford University Press, 1978); P. Thompson, 'Britain Strikes Back: Two Hundred Years of "Oral History,"' *Oral History Association Newsletter*, Vol. 15, (1981); C. Morrisey, 'The Case for Oral History,' *Vermont History*, Vol. 31, (1963), pp. 145-155; J. Vansina, *Oral Tradition: A Study in Historical Methodology* (Routledge, 1965); S. Benison, 'Reflections on Oral History,' *American Archivist*, Vol. 28, (1965), pp. 71-77; and A. Seldon and J. Pappworth, *By Word of Mouth: 'Elite' Oral History* (Methuen, 1983).

532 K. Worpole, 'A Ghostly Pavement: The Political Implications of a Local Working-class History,' in R. Samuel (ed.), *People's History and Socialist Theory* (Routledge and Kegan Paul, 1981), pp. 23-25.

533 A. Seldon and J. Pappworth, *By Word of Mouth: 'Elite' Oral History* (Methuen, 1983), pp. 17-20.

historian conducts and records an interview, as well as the words and phrases they use to elicit a specific type of responses. William Moss asserted that the way an interviewer plays their role 'often determines not only the tone and character of the record produced but also the substance of the record's content.'[534] Through shining a spotlight on the interviewer's methods and approach to the interviewee, the theoretical turn meant that oral history began to be treated more as a dialogic, 'textual' interaction.

The textual approach to oral history resulted in a series of publications that began to use oral history differently, including Elizabeth Tonkin's *Narrating Our Pasts: The Social Construction of Oral History* (1992). In it, she asserts that oral histories provide 'representations of pastness,' rather than history and that all speakers have 'purposeful social actions.'[535] She goes onto describe a 'social structuration of recall,' whereby individuals compose their responses to questions based on whether they believed their perspective was 'supported or threatened by public presentations of pastness that seem to either guarantee their identity or to deny its significance.'[536] Penny Summerfield's *Reconstructing Women's Wartime Lives: Discourse and Subjectivity in Oral Histories of the Second World War* (1998) built on this by exploring subjectivity and intersubjectivity through an analysis of forty-two post-war oral histories. She discusses how she perceived two groups ('heroes' and 'stoics') that participants embodied when composing their stories about the war, before highlighting that it was her intersubjectivity that had resulted in their voices being grouped into one of

534 W. Moss, 'Oral History: An Appreciation,' *American Archivist*, Vol. 40 (4), (1977), pp. 429-430; and S. Barber, and C. M. Peniston-Bird, *History Beyond the Text: A Student's Guide to Approaching Alternative Sources* (Routledge, 2009), p. 3.

535 E. Tonkin, *Narrating Our Pasts: The Social Construction of Oral History* (Cambridge University Press, 1992), p. 3.

536 Ibid., p. 10.

the two discursive possibilities.[537] While my main aim was to work with the Meccanomen to co-curate participant historiographies, I also decided that it would be useful to try and group the historical perspectives of the Meccanomen in the same way as Summerfield. The sections below will demonstrate that I initially tried to create these groups using their demographic data. They will then establish that the vast majority of respondents composed responses based on their personal experiences that did not fit with the conventional public history of Meccano. As will be demonstrated, this meant that the groupings of age, gender, and education were not the best way to categorise their answers. Instead, the sections will highlight a different set of groups that emerged for the responses to each question.

This theory of 'composure' has also become a prominent aspect of oral history since the theoretical turn. Initially articulated by Graham Dawson as a concept with dual meanings, he explains that interviewees experience positive composure when they endeavour to compose a 'life-story' comprised of 'personal narratives that are in accordance with prevailing discourse.'[538] Alistair Thomson's research into popular memory theory in practice is another example of this, in which he asserts that participants compose answers that are 'acceptable' to their self-identity and the language of their culture.[539] Summerfield's article, 'Culture and Composure: Creating Narratives of the Gendered Self in Oral History Interviews' (2004) built on the idea of composure by suggesting the concept of 'discomposure.' She asserts that 'discomposure' occurs when a participant composes a response in the hope of 'eliciting recognition and affirmation from his or her audience,' but does not receive it. She links the

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[537] S. O. Rose, 'Methods/Review,' Review of *Reconstructing Women's Wartime Lives: Discourse and Subjectivity in Oral Histories of the Second World War*, by P. Summerfield, *American Historical Review*, Vol. 105 (1), (2000), pp. 172-173.
[538] G. Dawson, *Soldier Heroes: British Adventure, Empire, and the Imagining of Masculinities* (Routledge, 1994), p. 22; and 247 https://www.tandfonline.com/doi/pdf/10.1080/09612025.2011.556322?needAccess=true
[539] A. Thomson, 'Anzac Memories: Putting Popular Memory Theory into Practice in Australia,' *Oral History*, Vol. 18 (1), (1990), p. 25.

occurrence of discomposure to one of two things: an unsympathetic response from their audience (for the Meccanomen, me as their interviewer, and for the OHBS voices, the staff who interviewed them), or a question that leads to a particularly challenging memory or line of inquiry.[540] Summerfield asserts that discomposure occurred for many of her participants when their answers deviated from established discourses. Juliette Pattinson developed on this idea in her re-examination of gendered intersubjectivities in interviews with British war veterans, asserting that discomposure is produced when there is an 'absence of cultural representations that validate a narrator's memories' when composing their life story.[541]

In the context of these interviews, I expected that many of the Meccanomen would experience discomposure. This was because my approach was designed to challenge the conventional public history of the Meccano on which their membership as Meccanomen was based. However, after my initial interview with Matt Goodman, I noted that he did not appear to experience discomposure, despite the majority of his responses deviating from the conventional public history of Meccano and the Meccanomen clubs. Instead, he appeared to enjoy discussing the problems with previous public histories and contrasting them with his own view, exhibiting what could be considered to be composure. In hindsight, the lack of discomposure suggests Goodman did not validate his memories using the cultural representations provided by the conventional public history of Meccano. That the majority of his answers were based on his personal experiences further suggests that his memories and knowledge of Meccano were not validated by his status as a Meccanoman. Instead, it appears that he composed his answers based on his belief that he has ownership over the hobby.

540 P. Summerfield, 'Culture and Composure: Creating Narratives of the Gendered Self in Oral History Interviews,' *Cultural and Social History*, Vol. 1, (2004), p. 69.

541 J. Pattinson, 'The Thing That Made Me Hesitate…': Re-examining Gendered Intersubjectivities in Interviews with British Secret War Veterans,' *Women's History Review*, Vol. 20, (2011), pp. 245-263.

Subsequently, one of the aims of these interviews was to see if other Meccanomen had similar personal ownership over their hobby, which meant they did not experience composure when giving a perspective that did not fit with the conventional public history of Meccano.

Paul Merchant's forthcoming article, 'What Oral Historians and Historians of Science can Learn From Each Other' (Upcoming) focuses on the relationship between the work completed by oral historians and historians of science. He uses the article to make three suggestions for how these two fields can more critically engage with each other to produce better ways to analyse and understand interviewee's scientific reflections on the past.[542] The first and third of his suggestions are for how historians of science can effectively use oral history in their research. These are considered below in the context of the interviews conducted with the Meccanomen. His first suggestion calls on historians of science to learn from the theoretical turn in oral history and extend their critical analysis of texts into the interviews they conduct with scientists. He also suggests that they go beyond measuring the accuracy of recall and instead take a greater interest in the way that wider social and cultural factors impact people's composed narratives. He also calls on historians of science to engage with the concept of composure and approach interviews as socially and culturally bound responses. The issues of the Meccanomen's composure and discomposure were central themes in the interviews I conducted, in relation to their view of British engineering, which helps to answer this aspect of Merchant's call to historians of science.

Merchant's second suggestion was for oral historians to incorporate the analytical techniques of historians of science in their practice. While I am not an oral historian, the

[542] P. Merchant, 'What Oral Historians and Historians of Science can Learn from Each Other,' *Upcoming in British Journal for the History of Science*.

interviews below demonstrate the benefits that there may be for oral historians that incorporate these aspects into their research. His third suggestion calls for historians of science and oral historians to combine different ways of analysing interviews when using the same outputs. The example he cites is Summerfield, who believed that her interviews with women in the Home Guard allowed her to demonstrate how some struggled with the issue of composure and sought to 'revise the historical record.'[543] My interviews with the Meccanomen also answer this part of Merchant's call by exploring their composure (and discomposure) and grouping their historical reflections to better understand the salience of the conventional public history of Meccano among the Meccanomen and the voices from the OHBS archives.

While my interview approach answered these calls from Merchant for historians of science to engage more closely with recent oral history scholarship, the unusual approach of creating more of a two-way, participatory interview scenario based on the public history concept of Michael Frisch's 'shared authority' represented a step beyond what he suggested.[544] It did this by creating an interview scenario where the Meccanomen and I could challenge each other on aspects of the conventional public history of Meccano, and work together to co-curate their participant historiographies.

In contrast to oral history, public history is an approach to writing history that was developed to bridge the gap between the public and knowledge created by historians (as part of the History Workshop Movement).[545] Hilda Kean, Paul Martin, and Sally Morgan describe

[543] P. Summerfield, 'Oral History as an Autobiographical Practice,' *Miranda*, Vol. 12 (3), (2016), pp. 3-4.
[544] M. Frisch, *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (University of New York Press, 1990), p. xxii.
[545] The History Workshop Movement was an alternative movement established by Raphael Samuel in the 1970s as a way of encouraging 'history from below.' For more on this movement, refer to R. Perks, *Oral History: Talking about the Past* (British Library National Sound Archive, 1992); and B. Schwarz, 'History on the Move: Reflections on History Workshop,' *Radical History Review* Vol. 57, (1993), pp. 203-220.

how good public history should bring together diffuse groups of people, which allows us to examine the 'historical-self' at a given movement in time or space.[546] Similarly, Ludmilla Jordanova asserts that public history allows us to learn more about how non-professional historians acquire their sense of the past.[547] Perhaps the most prominent example of public history is how museums have begun to co-curate exhibitions in partnership with communities that are a part of that history. An example of this was the 'Brothers in Arms' initiative at the National Army Museum in London in 2015, which saw the museum working with members of British Asian communities to reinterpret and understand their collection of objects differently. Practical examples included members of the public identifying previously unknown individuals and locations in photographs and translating inscriptions that led to new object understandings. Jasdeep Singh Rahal, the project officer for the 'Brothers in Arms,' explained that working with the public uncovered a lack of institutional knowledge about the collection and that as a result 'gone are the days when a curator's interpretation was seen as unassailable.' He describes how conversing with audiences, and co-curating exhibitions with them allowed their cultural insight and expertise to become part of the museum, which led historical knowledge to be presented in a way that can be more easily consumed by non-specialist curators and historians.[548]

In the context of conducting interviews, Linda Shopes asserts that to pursue Frisch's 'shared authority' effectively, the interviewer needs to critically engage with the respondent's perspectives by creating a space where the interviewee and interviewer can 'agree to

[546] H. Kean, P. Martin, and S. J. Morgan (eds.), *Seeing History: Public History in Britain Now* (Francis Boutle Publishers, 2000), p. 13.
[547] L. Jordanova, 'Public History,' *History Today*, Vol. 50 (5), (2000).
[548] The development of science centres and interactive exhibits in the second half of the twentieth century are discussed in R. Toon, 'Science Centres: A Museum Studies Approach to their Development and Possible Future Direction,' in S. J. Knell, S. MacLeod and S. Watson (eds.), *Museum Revolutions: How Museums Change and Are Changed* (Routledge, 2007), pp. 106-133.

disagree' on subjects.[549] My approach combined elements of how museums have co-curated exhibits with Shopes' and Frisch's work on 'shared authority,' using them to create an interview scenario that allowed me to combine the dialogic processes of oral history with the interpretative and participatory processes of public history. This participatory approach allowed me to work with the Meccanomen to co-curate new understandings of Meccano as a scientific object, by combining elements of their oral histories with these concepts from public history.

Before conducting these interviews with the Meccanomen, I contacted various club officers in May-June 2016 as I wanted to ensure that from the outset, the interview process and questions had been designed based on a 'shared authority' between the Meccanomen and myself. In my initial email, I introduced the perspectives of Meccano as a homogenous engineering object from Wainman's and Brown's academic works, alongside the conventional public history of Meccano as a synecdoche for the 'golden age' of British engineering.[550] I then asked if they thought their members would have opinions on the 'golden age' of Meccano, the co-location of this 'golden age' with the 'golden age' of British engineering, and the link between the demise of Meccano and popular belief in a national decline in Britain. I also asked them to reflect on these aspects of the conventional public history and tell me if they believed that they were pervasive themes in their clubs today.

In response, a number told me that these themes had been present in the earliest issues of the *Meccanoman's Journal* and the *Meccano Engineer* and that although they had

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[549] L. Shopes, '"Insights and Oversights": Reflections on the Documentary Tradition and the Theoretical Turn in Oral History,' *The Oral History Review*, Vol. 41 (2), (2014), pp. 265-266.
[550] R. Wainman, '"Engineering for Boys": Meccano and the Shaping of a Technical Vision of Boyhood in Twentieth-Century Britain,' *The Journal of the Social History Society*, Vol. 14 (3), (2017), pp. 381-396; K. D. Brown, *The British Toy Business: A History Since 1700* (Bloomsbury, 1996); K. D. Brown, *The British Toy Industry* (Shire Publications, 2011); and Kroto's interview in which he discussed the 'demise of British engineering' was on a BBC Radio 4 episode of *Desert Island Discs,* https://www.bbc.co.uk/programmes/p00948nr [accessed 4 July 2016].

been much less prevalent in publications during the last few decades, members were still aware of the concepts. The majority said that they believed their members would have opinions on how the history of their hobby had been written, though they were not sure if they would be positive or negative. One respondent told me that it would be 'interesting to see what they say, as it is the first time they have been asked.'[551] These responses confirmed that the majority of previous histories of Meccano had been created without considering the voices of the contemporary Meccanomen. Therefore, I was interested to see what kind of answers the interviewees would compose when I placed them in a position of responsibility as representatives of the Meccanomen movement, and whether they would compose participant historiographies that did or did not fit with the conventional public history of the Meccanomen movement.

From October 2016 to October 2018, I systematically interviewed 126 members of clubs, societies, and guilds. This number represented just over 20% of the total membership of the official Meccano clubs in Britain that come under the International Society of Meccanomen.[552] The majority of these interviews were conducted face-to-face, with telephone conversations utilised to make sure that the voices of members from more northerly clubs could also be captured.[553] The interview process was designed to last between 45 minutes to one hour, with the Meccanomen answering ten questions (see appendix two).[554] However, rather than making sure that every Meccanomen answered every single question, I used them more as a guideline to steer the interviews towards the themes that I

[551] Joshua Adamson, personal correspondence, 2 August 2016.
[552] These 600 members are those who are part of clubs that come under the umbrella of the 'International Society of Meccanomen' in the UK. Other clubs do exist in the UK and abroad, but are unaffiliated to the organisation.
[553] The list of these clubs is available at http://internationalmeccanomen.org.uk/ISM/Societys/soc.html [accessed 20 September 2016].
[554] See Appendix Two for the list of interview questions used.

felt they would have an opinion about, or when a discussion reached its natural conclusion. Due to the conversational nature of the interviews, which involved lots of back-and-forth debate about different aspects of Meccano and its public history, most interactions lasted upwards of two hours, with one lasting three-and-a-half.[555]

The second section of this chapter analyses the development of decline in both an academic and popular context, before exploring the topics of 'golden ages' and decline in the context of other enthusiast groups. It demonstrates the popularity of these concepts in Britain and helps to provide further context as to why I chose to interview the Meccanomen in a way that meant we could work together to co-curate their historiographies on these topics in relation to Meccano. The third section analyses the demographic data of the Meccanomen and establishes that while there were some correlations between a respondent's age, gender, and education level and how they compose their answers, they were insufficient to categorise their historical perspectives. The subsequent three sections then analyse the respondents' qualitative answers to questions about the 'golden age' of Meccano, the 'golden age' of British engineering, and the notion of a British decline. The sections separate the historical perspectives of respondents into various groups, while also establishing that when given the opportunity, some composed participant historiographies that critiqued aspects of the conventional public histories of Meccano. Each of these sections will demonstrate that while there was no consensus among the Meccanomen's answers to these questions, none appeared to experience discomposure, despite their responses deviating from the conventional public history of Meccano.

[555] I also told each Meccanoman that their personal details would not be used in this thesis, in order to make them feel more comfortable making potential critiques of their hobby and the Meccanomen movement. To this end, the chapter uses pseudonyms for all those interviewed, except for Matt Goodman and Geoff Wright (who feature prominently in other chapters of this thesis), along with the voices from the OHBS archives.

2. 'Golden Age' and Decline

The popular belief in a national decline featured intermittently in British culture throughout the twentieth century and has been described as 'the British disease' by academics.[556] The popular declinist thesis is often used to reflect on how things were better in the past 'golden ages' try and explain societal changes. In contrast to this, the academic declinist thesis posited that the British 'golden age' – in industry, engineering, and culture – occurred before the mid-twentieth century and ended after the Suez Canal crisis in 1956.[557] The popularity of the thesis increased in an academic context after the publication of Martin Wiener's *English Culture and the Decline of the Industrial Spirit, 1850-1980* (1981), and Correlli Barnett's *The Audit of War: The Illusion and Reality of Britain as a Great Nation* (1986).[558] Wiener's central argument was that British industry and engineering experienced an entrepreneurial failure in the 1950s and 1960s, due to the decrease of science and engineering candidates attending university after the Second World War.[559] This decrease in university applications was framed as part of the broader 'British disease' of an increasing 'cultural conservatism' after the war, which Wiener argued was at the heart of Britain's industrial deficit since the Second World War.[560]

Barnett's work developed aspects Wiener's argument, asserting that this increase in 'cultural conservatism' had meant that only 12.5% of school leavers entered skilled trades

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[556] For examples of this, refer to G. C. Allen, *The British Disease* (London, 1976), and B. Elbaum, and W. Lazonick, 'The Decline of the British Economy: An Institutional Perspective,' *The Journal of Economic History*, Vol. 44 (2), (June, 1984), pp. 567-583.
[557] D. Brown, '1956: Suez and The End of Empire,' *The Guardian*, (14 March 2001), https://www.theguardian.com/politics/2001/mar/14/past.education1 [accessed 5 December 2016].
[558] M. J. Wiener, *English Culture and the Decline of the Industrial Spirit, 1850-1980* (Cambridge, 1981); and C. Barnett, *The Audit of War: The Illusion and Reality of Britain as a Great Nation* (Pan Books, 1986).
[559] M. J. Wiener, *English Culture and the Decline of the Industrial Spirit, 1850-1980* (Cambridge, 1981), p. 135.
[560] Ibid., pp. 135-136.

and 6.25% entered an industry in the decade following the Second World War.[561] He argued that the post-war construction of the welfare state had exacerbated the process by which British industry was lost in the 'schoolyards and quadrangles' of Britain's institutions.'[562] Together, these publications became known as the Wiener-Barnett thesis of cultural decline. The central theme of the thesis was that British industry declined after the Second World War because science and engineering became the preserve of the low-status practical men, who used 'backward rule of thumb methods.'[563] Many of the themes of Wiener's work echoed aspects of the Scarman Report that was also published in 1981 after the Brixton riots. Wiener's description of the 'British disease' echoed the assertion made in the Scarman Report that called for urgent action to prevent '…disadvantage [in Britain] from becoming a disease threatening the very survival of our society.'[564] Although these criticisms of a non-technically educated workforce were not new (having featured before both the First and Second World Wars), the cultural context of Britain in 1980 – with inflation above 10% and unemployment reaching 2.5 million – meant that the notion of a 'British disease' found a new audience.[565]

Despite its initial salience as an explanatory tool of change during the 1980s, the validity of Wiener-Barnett thesis began to be increasingly questioned throughout the 1990s.[566] Bruce Collins and Keith Robbins, for example, asserted that the academic declinist

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561 C. Barnett, *The Audit of War: The Illusion and Reality of Britain as a Great Nation* (Pan Books, 1986), p. 304.
562 Ibid., p. 304.
563 D. Edgerton, '*Science, Technology, and the British Industrial 'Decline,' 1870-1970*' (Cambridge University Press, 1996), p. 15.
564 Lord Scarman, 'The Scarman Report: The Brixton Disorders, Report of an Inquiry: 10-12 April 1981,' https://books.google.co.uk/books?id=inKwAAAAIAAJ&q=scarman+report&dq=scarman+report&as_brr=0&cd=1&redir_esc=y [accessed 23 November 2016].
565 D. S. L. Cardwell, *The Organisation of Science in England* (London, 1957); F. Turner, 'Public Science in Britain, 1880-1919,' *Isis*, Vol. 71 (4), (1980), pp.589-608; and K. Pavitt (ed.), *Technical Change and British Economic Performance* (London, 1980).
566 B. Collins and K. Robbins (eds.), *British Culture and Economic Decline* (London, 1990); D. Edgerton, '*Science, Technology, and the British Industrial 'Decline,' 1870-1970*' (Cambridge University Press, 1996); J. Tomlinson, *The Politics of Decline: Understanding Post-War Britain* (Pearson, 2001); and A. Sampson, *Who Runs This Place? The Anatomy of Britain in the 21st Century* (Hodder and Stoughton, 2004).

thesis overgeneralised the specific anti-scientific culture of Oxbridge to the wider British culture.[567] Anthony Sampson built on this perspective, highlighting that the anti-scientific culture of Britain after the war could not be related to the bias of a few elite institutions, but instead was related to a much broader set of structural issues from both inside and outside of Britain.[568] David Edgerton's works on British decline – beginning with *Science, Technology, and the British Industrial 'Decline'* – adopted a more empirical approach, demonstrating that, in contrast to the Wiener-Barnett thesis, the number of science and technology students had increased by 12.9% and 11.3% (respectively) at both 'plate glass' and Oxbridge universities between 1929 and 1968.[569] Edgerton's work established that it was Britain's relative, not its absolute economic position that declined after the war. Despite a significant number of academic publications that have provided evidence against the concept of declinism, the belief in decline and the idea of a 'British disease' has continued in a popular context.[570]

The success of the popular declinist thesis is based on the belief that it explains negative or unwanted changes in society by creating a sense of 'other.'[571] It encourages the public to look back on the past using 'rose-tinted glasses,' appealing to an idealised vision of yesterday that distorts reality by underemphasising negative and overemphasising positive aspects of the past. Two contemporary examples include Donald Trump's 'Make America Great Again' campaign, and Boris Johnson's urging of British voters to 'take back control of

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[567] B. Collins, and K. Robbins (eds.), *British Culture and Economic Decline* (London, 1990), p. 61.
[568] A. Sampson, *Who Runs This Place? The Anatomy of Britain in the 21st Century* (Hodder and Stoughton, 2004), p. 53.
[569] D. Edgerton, '*Science, Technology, and the British Industrial 'Decline,' 1870-1970*' (Cambridge University Press, 1996), p. 20.
[570] The continued prevalence of decline features in Edgerton's latest book, *The Rise and Fall of the British Nation: A Twentieth-Century History* (2018), which argues that a belief in declinism now defines British culture.
[571] This 'othering' often centres on 'undesirable' groups, framing them as having caused negative societal changes in Britain and around the world. It harks back to a 'golden age' as part of this process, reminding people that the 'others' didn't use to be in the position they currently have.

this great country's destiny…to transform Britain for the better.'[572] Despite a panoply of evidence that suggests that America is as 'great' as it has ever been and that Britain is indeed in control of its destiny, the popular declinist theses and 'golden ages' of these campaigns continue to resonate with their publics. However, the biggest challenge of popular declinism as a tool to explain change over time is that it often results in the creation of many – often conflicting – 'golden ages,' which led Tomlinson to reflect that 'at one time or another declinism indicted almost every possible feature of modern Britain as a cause of decline.'[573]

The BBC documentary *The Joy of (Train) Sets* (Andrew Hall, 2013) provides an example that demonstrates how the hobby of model train collecting has affected enthusiasts' perspectives of both a British 'golden age' and subsequent decline. The 'golden age' of model train collecting is built around the 'romance of the steam engine.'[574] For model train collectors, this 'romance of the steam engine' is based on the nostalgia of what the steam engine represented to them when they were children, overlooking the grease, heat, and noise of a fully functioning steam engine.[575] Their model train dioramas function as individual gateways to the lost 'golden age' of their childhood, presenting quixotic and distilled visions of the past that feature a perfect, unspoiled British countryside, where the sun always shone, and steam trains rumbled through the countryside on a clockwork schedule. How this 'golden age' and decline manifested was personal to each model train collector, and based on their experiences with their hobby. However, their oral testimonies rarely reflect the realities of a

[572] 'Make America Great Again,' https://www.donaldjtrump.com/ [accessed 20 June 2018]; and M. Hall, 'Boris Johnson urges Brits to vote Brexit to "take back control,"' *The Daily Express*, (20 June, 2016), https://www.express.co.uk/news/politics/681706/Boris-Johnson-vote-Brexit-take-back-control [accessed 8 June 2018].
[573] J. Tomlinson, *The Politics of Decline: Understanding Post-War Britain* (Pearson, 2001), p. 76.
[574] Mary Griffin, 'The Smell of Oil, Steam and Smoke - It's Why we're Model Railway Fans' *Birmingham Post,* (November 23rd, 2013), http://www.birminghampost.co.uk/lifestyle/nostalgia/attraction-playing-model-trains-6333524 [accessed November 20 2016]
[575] A. Hall, BBC Productions, 'The Joy of (Train) Sets - History of Model Railway,' (2013), https://www.youtube.com/watch?v=MmV5EOGirnI [accessed 10 November 2016].

country that had 25% of the population living below the poverty line, or one whose citizens' livelihoods had been ruined by the effects of the Great Depression and impacted by the night-time raids of the Second World War.[576] This type of disjuncture with the realities of the past sustains the idea that there has been a terminal decline in Britain's economy and industry. The prominence of 'golden ages' and decline in both an academic and popular context in Britain throughout the last half-century (during the lifetimes of the Meccanomen that I planned to interview), provided further confirmation that the interviewees would have interesting opinions and perspectives on these themes in relation to Meccano.

[576] M. Ravaillion, 'Poverty: The Past, Present, and Future,' https://www.weforum.org/agenda/2016/01/poverty-the-past-present-and-future/ [accessed 7 September 2017].

3. Membership and Age, Gender, and Education

	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990
Percentage of participants born	18%	40%	30%	6%	4%	2%

Figure 6.1: The ages of the Meccanomen interviewed for this chapter, expressed as percentages per decade. It demonstrates that 88% of members born before 1961.

Figure 6.1 illustrates that the majority of Meccanomen interviewed were born before 1961, with only 12% born in the years since. These percentages suggest that – with an average age of 68.1 years old – retirement is an influential factor in their membership. The demographic data of the Meccanomen also reveals that the majority of interviewees were born after the Second World War. This means that a high proportion of the 67% of Meccanomen who later told me that they had lived through the 'golden age' of Meccano could not have been referring to the same pre-war 'golden age' as the one at the foundation of the conventional public history of Meccano.[577] The reason for this became clearer when I asked officers from different clubs what purpose they believed their clubs and societies fulfilled for their members. John Light was the first to respond, telling me that the clubs were 'A social gathering where our somewhat old and eccentric hobby is not only acceptable but regarded as the norm?'[578] Similar to Light, Paul Higson stated that clubs provided members 'a way to avoid loneliness in our old age.'[579] It is interesting that while both referenced old age, neither referenced the conventional 'golden age' of Meccano or alluded to recapturing nostalgia as a purpose of their clubs. As well as this, neither also seemed particularly concerned with the nostalgia or 'golden age' elements of their hobby being a part of their club, despite both of their clubs being part of the International Society of Meccanomen that

[577] R. Marriott, *Meccano* (Shire Publications, 2016), p. 24.
[578] John Light, personal correspondence, 27 July 2016.
[579] Paul Higson, personal correspondence, 28 July 2016.

continues to have these 'golden age' and nostalgic aspects as two parts of their organisational aims.

Two other responses to this question contained slightly more explicit allusions to how the clubs provided a way to return to a 'golden age.' The first was from Joshua Adamson, who asserted that the clubs provided 'a way to reach back to (arguably) happier and (probably) simpler times when we were young (whether those times were genuinely better or not).'[580] While Adamson's response references how his club allowed members to indulge their nostalgia, his words in parentheses demonstrate that he had reservations about this whether or not this was a realistic function for all members. Similar to this, Bill Ramsey said that the clubs gave 'a chance for some of the older members to simply meet up, have a cuppa, and talk about the old days while they complain about the Government, kids today, the NHS, Brexit, etc.'[581] His response highlights that while he does believe that his club allowed members to recapture the old days, he does not explicitly link this 'golden age' to Meccano, but more to an overall decline in Britain. These four responses suggest that there is no consensus among the officers on whether their clubs provide a means to return to a 'golden age,' but that even when they do believe that they do, the 'golden ages' that they referred to did not fit with the conventional public history of Meccano, which occurred before the majority were born. Therefore, based on this analysis, age is not a good basis on which to group the answers of the Meccanomen, as it does not appear to have a large bearing on their perspectives.

The second piece of demographic data from the Meccanomen is their gender, with only four out of 126 members interviewed being women (despite my best efforts to include

[580] Joshua Adamson, personal correspondence, 2 August 2016.
[581] Bill Ramsey, personal correspondence, 30 August 2016.

as many women as possible). All of the women I interviewed critiqued the conventional 'golden age' history of the Meccanomen, with Sam Thomson stating that 'clearly, I am proof that Meccano is not completely a boy's toy…I am not trying to reinvigorate that so-called gold[en] age.' I then asked her what she thought of the prevalence of the conventional public history of Meccano as a 'boy's toy' in previous histories of her hobby. She replied, telling me that 'they had been written by people who don't understand that girls used Meccano too.'[582] Perhaps unsurprisingly, none of the 'Meccanowomen,' exhibited outward signs of discomposure during our interviews, despite all composing participant historiographies that did not fit with the conventional public history of Meccano.

The Meccanowomen's critique that historians have focused on the relationship between men and Meccano at the expense of women also featured in the five women's interviews (that featured among the ninety-six Meccano enthusiasts) in the British Library Oral History Archives. These include Faith Shannon [Artist] who described how her father gifted her a Meccano set as a child after she demanded it and Margherita Rendel [Social Welfare Campaigner] who stated that she did not want dolls as a child, but asked for a train set and Meccano outfits.[583] Their examples contrast with the conventional public history of Meccano that situates it as a boy's engineering tool. The voices of the Meccanowomen and the women Meccano enthusiasts demonstrate that their perspectives are critical of the way that previous Meccano histories have not included them. However, as the sample size was so small in both examples, it became clear that gender would not be a good basis on which to categorise the responses of the wider sample.

[582] Sam Thomson, personal interview, 29 October 2017.
[583] Faith Shannon, interviewed by Hawksmoor Hughes, 2 December 2004, C960/34, https://sounds.bl.uk/Oral-history/Crafts/021M-C0960X0034XX-0005V0 [accessed 24 October 2016]; and Margherita Rendel, interviewed by Louise Brodie, 30 June 2016, C1155/29, https://sounds.bl.uk/Oral-history/Charity-and-social-welfare/021M-C1155X0029XX-0003V0 [accessed 25 October 2016].

The final piece of demographic data from these interviews concerns the educational attainment of members, with 58% of those interviewed holding degrees. Among this 58%, just under 63% held degree-level qualifications in engineering; 29% in science, mathematics, or computing; and 8% in humanities or medical disciplines. When I asked the interviewees whether they thought that Meccano had brought a benefit to their lives, 98/110 of the interviewees that believed it had, also held advanced qualifications in any subject beyond A-Level study, with only one of the 58% of degree holders disagreeing. This statistic demonstrates that the majority of the respondents believed that Meccano had taught them skills that have been useful in their careers, even when their careers were not specifically engineering or science-based.

Among the remaining sixteen respondents who did not believe that Meccano had brought benefits to their lives or careers, fifteen did not have any qualifications at an advanced level. Within this group, Michael Howell believed that '…[Meccano] is a serious hobby, but it has added nothing to my working life,' while Lauren Kearney felt that it was '…simply a fun thing to do in my spare time.'[584] David Hodges echoed these sentiments, explaining that for him Meccano was about 'Enjoyment only, mainly around the fellowship associated with being a member of one of the club.'[585] The only respondent in this group that held an advanced qualification was John Simmonds, who held a degree in chemistry. Nevertheless, his perspective of Meccano was similar to the other fifteen in this group, as he believed that it provided 'Nothing very profound other than enjoyment…though it is a great conversation starter when I have cocktail parties.'[586] Correspondingly, only four of these

[584] Michael Howell, personal interview, 16 October 2016; and Lauren Kearney, personal interview, 21 October 2016.
[585] David Hodges, personal interview, 17 April 2017.
[586] John Simmonds, personal interview, 27 September 2017.

sixteen respondents agreed that an increase in Meccano among the younger generation would benefit the national good of Britain. The other twelve from this group that disagreed represented 75% of those in the overall sample who disagreed that a return to Meccano could help to reverse a decline in Britain. Their responses suggest that the level of education may be a useful way to separate the historical and historiographical perspectives of the Meccanomen. However, the variety of their qualifications (outside of science and engineering) made it difficult to group their answers and perspectives in any meaningful way for the aspects of the Meccano hobby and public history this chapter focused on.

Therefore, while the three examples of demographic data in this section suggest future areas for research – particularly the issues of female-representation and the correlation with education – they were not useful groups to separate the perspectives of the sample. Instead, the following sections suggest distinctive groups for the answers given to each question, which demonstrate that there was no broad consensus among the Meccanomen on these issues. The sections also establish that the majority did not experience discomposure, despite their perspectives contrasting to the conventional public history of Meccano.

4. The 'Golden Age' of Meccano

This section focuses on the question, 'Was there a 'golden age' of Meccano, and were you a part of it?' This question was designed to challenge the respondent's identities as representatives of their clubs and the International Society of Meccanomen, by getting them to reflect on the conventional public history of Meccano that places the 'golden age' before the Second World War. Of the 126 respondents that were interviewed, 86% believed that there was a 'golden age' of Meccano, with 67% of asserting that they were a part of it. As discussed in the previous section, the age demographics of the sample (that established that only 18% of the sample were born before 1940) immediately demonstrate that the majority of this 67% could not be referring to being a part of the conventional 'golden age' of Meccano that was before the Second World War.

When I asked other Meccanomen whether there had been 'golden age' and if they were part of it, many commented that while they had not been part of the conventional 'golden age,' they believed that Geoff Wright, whom they described as 'the saviour of Meccano' and the 'driving force behind returning Meccano to its former glory,' had been part of it.[587] Wright was discussed in Chapter Five as one of the few original Meccanomen who helped to establish an 'alternative' version of Meccano after 1965, through developing MW Models and the Henley Society of Meccano Engineers.[588] Therefore, prior to interviewing Wright, I assumed that he (as one of the 18% born before the war) would be part of the 67% that believed he had been part of the 'golden age' of Meccano. However, I was surprised by his answer that 'The 'golden age' is right now.' I responded by outlining the conventional

[587] Jack Linson, personal interview, 16 October 2016; David Hodges, personal interview, 17 April 2017; and Richard Hudson, personal interview, 18 April 2018.
[588] 'Golden Spanner Award 2007: Geoff Wright,' http://internationalmeccanomen.org.uk/ISM/GSAward/album/2007%20Geoff%20Wright%20%20(United%20Kingdom)/slides/03%20Geoff%20in%20Meccano%20Wonderland.html [accessed 18 August 2017].

'golden age' of Meccano that defined the early days of the movement that he had set up, and that continues to define the International Society of Meccanomen today. In response, he told me that this was 'too narrow a view' of the 'golden age,' and that by 'right now' he was referring to the 'quality of the models' that were produced in Meccano clubs, and not the overall popularity of the clubs or economic success of the toy. He explained how in his experience, the previous histories of Meccano had placed too much of an emphasis on the economic fortunes of Meccano Ltd., and ignored how the Meccanomen had reinvigorated and continually changed the hobby since 1965.

When I questioned him about his status as one of the original Meccanomen, he told me that his nostalgia for a return to a 'golden age' had changed when he realised that with each passing year of the clubs he had seen 'something more impressive achieved with it [than the year before].' His responses confounded the conventional public history of Meccano by providing a critique about how previous histories have been written. His explanations of why his perspective has changed over time also demonstrated how the Meccanomen – like the Meccano boys discussed in Chapter One – have been mistakenly written about as a homogenous group of users. Throughout our discussion, I noted that Wright did not experience discomposure. Nevertheless, I asked him how he felt about his critical perspectives of the conventional public history of the hobby that he had helped to establish. In response, he told me that it did not matter to him as he had 'loved Meccano through [his] entire life,' and nothing would change that.[589] His response suggested that he did not experience discomposure because his perspective was comprised of his personal histories

[589] Geoff Wright, personal interview, 28 November 2016.

and experiences with Meccano, rather than his membership to the International Society of Meccanomen and their pre-war 'golden age' of Meccano.

Another example of the complex and nuanced answers came from Nigel Cookson, who asserted that he had been a part of the 'golden age' of Meccano, but that it had been during the 1970s and 1980s. He explained that since then, 'Meccano clubs, societies, and guilds are on a downward spiral and that in this regard, the 'golden age' [of Meccano] is over.' When I described the conventional 'golden age' and demise of the Meccano, he shook his head and said 'No, the reality is that the [Meccano] clubs have declined from their 'golden age' over the past few decades as it has become harder to get younger members to join up.' When I asked him to elaborate on this, he told me that this type of decline from a 'golden age' was 'not unique to Meccano, but a reflection of changing times and the evolution of modern culture… [and that] a similar story applies to model railways, model boats, model aeroplane clubs, and others.'[590]

I then asked Cookson if he thought other Meccanomen would want to return to the 'golden age' of Meccano clubs that he had described. His answer came in two parts, with the first part demonstrating that he supported the idea of a 'golden age' and the second part establishing that he did not agree that a return to this 'golden age' would be a good thing. He told me, 'I think that all members of Meccano clubs would like to return to a time when these clubs were really busy, and toy shops were filled with Meccano and Airfix and Keil Kraft.' After pausing for a second, he then mentioned that '…if clubs were still really buoyant, then would we appreciate them or take them for granted? Would we get cheesed off that the clubs were so busy and you could never find a spare bit of table-top to display your model? ...I don't

[590] Nigel Cookson, personal interview, 11 September 2017.

know.' Therefore, in a similar manner to Wright, Cookson's answers did not fit with the concept of the conventional 'golden age' as they were based on his personal experiences. Throughout our subsequent discussion about the conventional public history of Meccano and the Meccanomen, Cookson also did not appear to experience discomposure, despite critiquing many different aspects of how it had been written. Instead, similar to Goodman, he appeared to enjoy the debate, asking me if I would be willing to join his club as I would 'bring the average age down significantly.'[591]

When I asked Robert Nurse if there had been a 'golden age' of Meccano and if he had been a part of it, he told me that if I had asked him those questions two decades ago, he would have situated the 'golden age' of Meccano in the 1930s. However, he explained that since that generation had now 'broadly died off,' the clubs were no longer focused on their desire to 'recapture the glories of the past.' When I explained to Nurse that the International Society of Meccanomen website still referenced the conventional 'golden age,' he initially shrugged his shoulders and shook his head. He then told me that what is written there does not reflect the reality of the Meccano clubs in the UK as far as he sees it. He explained that although 'that "golden age" may have been true in the past,' the clubs had since been 'redesigned to support their members' creation of new models, whether they were models that would win "national prizes" or were childlike in their simplicity.'[592] He told me that I would see this during my interviews with other Meccanomen and if I managed to attend the public events run by their clubs, which I subsequently did and will discuss towards the end of this section.

[591] Nigel Cookson, personal interview, 11 September 2017.
[592] Robert Nurse, personal interview, 11 February 2017.

Similar to Nurse, Colin Gray asserted that '…the generation you refer [to] with that question has broadly passed on, so the sentiments of the 'golden age' are no longer there in the same way…the current generation of members has a much wider interest in other models.'[593] Both Nurse and Gray had been original members of the Meccanomen movement when it had sought a return to the conventional 'golden age' of Meccano. However, their responses both alluded to the idea that the histories written about their hobby were 'pre-occupied' with the past, rather than how they and their Meccano clubs had changed.[594] Their answers, along with Wright's, suggests a first way to group the responses to this question. This grouping is comprised of those who believed that while a conventional nostalgia for the 'golden age' had existed at one point, their understanding of what the 'golden age' was had developed and changed as a result of the personal experiences within their clubs.

While Dale Rimell's perspective confirmed aspects of Gray's and Nurse's responses about the changing nature of Meccano clubs, his answers were placed in a separate group of Meccanomen. The reason for this was that when I asked him about the 'golden age' and if he had been a part of it, he told me that he had joined the MSS in 2005, roughly 20 years after the club was formed and 40 years after the first Meccanomen clubs had been established. He explained that this time gap meant that the 'motivation of the founding members [had] more to with wishing to meet fellow hobbyists in order to exchange news, views, skills, and experience,' and less to do with a 'desire to return to a so-called golden age.'[595] When I asked Rimell if he believed in a 'golden age' of Meccano and whether he had been a part of it, he answered no, stating that the 'so-called 'golden age' apparently took place just before I was born [in 1960].' During our discussion, he made me search for the constitution of the Meccano

[593] Colin Gray, personal interview, 16 October 2016.
[594] Robert Nurse, personal interview, 11 February 2017.
[595] Dale Rimell, personal interview, 31 October 2018.

Society Scotland (MSS) on my laptop. He told me it provided evidence for his perspective because it stated that the aim of the society was to 'foster interest in the Meccano system,' along with the fact that there were no references about returning to a 'golden age.'[596] He explained to me that newer clubs like the MSS tended to be described using the same conventional 'golden age' public history of Meccano, despite the club being founded by the second generation of Meccanomen who did not have the same nostalgia. He then added that it was 'just [his] experience…but there are a few nostalgic purists left, and they are by no means the predominant group.' Rimell's perspective (along with Matt Goodman's) further highlighted that the second generation of Meccanomen had been underrepresented in the histories of the toy. In contrast to the mostly first-generation Meccanomen interviewed above, his perspective – as a second-generation user – meant that he doubted the existence of the 'so-called' 'golden age' altogether, rather than seeing it as something that had existed, but later developed and changed.[597]

Despite their differences, these groups both suggested that the Meccano clubs had moved away from the conventional public history of the 'golden age' of Meccano that governs the International Society of Meccanomen. To test this, I visited a series of Meccanomen events at Nurse's suggestion, beginning with the Telford and Ironbridge Meccano Society (TIMS) event 'Meccanuity,' run each year at the Enginuity Museum near Shrewsbury since 2001. A preview piece from *B-C-ing-U!* travel and leisure magazine described the event in 2016 as 'a real family show, and there will be lots of Meccano parts available for youngsters to have a go at creating their own masterpieces.'[598] This description suggested that the event was not informed by the same nostalgia for a 'golden age' as features in the institutional aims

[596] Meccano Society of Scotland, https://www.meccanoscotland.org.uk/ [accessed 10 October 2016].
[597] Dale Rimell, personal interview, 31 October 2018.
[598] A. Evans, 'Meccanuity 2016,' http://b-c-ing-u.com/2016/04/25/22392/ [accessed 11 November 2017].

of the International Society of Meccanomen. I visited the event in 2016 and found that instead of a display of pre-war Meccano models, the event provided spaces for visitors to get their hands on many varieties of Meccano, alongside the member's constructed Meccano models. I was interested to see that instead of the pre-war red and green Meccano pieces that had dominated the early Meccanomen movement and been an emblem of their desire to return to a 'golden age,' the Meccano that was on display also included Themed Sets, 'Multi-kits,' and Plastic Meccano sets. The use of these sets – that were once maligned as having caused the demise of Meccano from its 'golden age' in the earliest issues of the *Meccanoman's Journal* in 1965 – demonstrates how members of this club had developed their hobby away from the conventional public history of Meccano (see figure 6.2).[599]

[599] G. Maurice Morris, *Meccanoman's Journal*, No. 1, (October, 1965).

Figure 6.2: The top image is from Meccanuity 2015, held at the Enginuity Museum. The bottom image is an example of how members of the clubs have a step away from the ‘pure’ Meccano sets and rhetoric of the past. (© Matt Goodman).

The shift that the Meccanomen suggested in their interviews was also apparent in events run by other clubs, including the Runnymede Meccano Guild, who have hosted an annual 'Marvels of Meccano' event at the Kempton Steam Museum since 2013.[600] It offers a comparable experience to Meccanuity, with Meccanomen demonstrating their creations alongside 'build your own model' stations that feature a variety of different Meccano kits, which were once blamed for the demise of the hobby (see figure 6.3). This structure of events was the same at several other events that I have visited throughout this thesis. They suggest that while the contemporary Meccanomen are aware of the conventional 'golden age' of Meccano, many clubs have moved their hobby away from it as the age demographics and desires of their members have changed.

Figure 6.3: The image on the left is the poster for the 'Marvels of Meccano' event in 2018 held at the Kempton Steam Museum. The image on the right is an example of how the clubs have tried to engage children with 'build your own model' stations. (© Matt Goodman).

600 'Marvels of Meccano,' http://www.kemptonsteam.org/marvels-of-meccano/ [accessed 20 October 2018].

This section has established two groups of responses to the question about the 'golden age' of Meccano and if they had been a part of it, which broadly split along the lines of whether they were first- or second-generation Meccanomen. However, regardless of their group or which generation they belonged to, the majority of respondents all composed participant historiographies that critiqued the concept of a 'golden age' that has featured in the conventional public history of Meccano and previous academic analyses. In some of these interviews, the Meccanomen were well aware that while they had developed and changed the version of Meccano in their clubs, this had not been reflected in the International Society of Meccanomen's constitution and aims.

The variety of their answers and the forcefulness with which they delivered them, supports the reinterpretation of Kroto's synchronic perspective of Meccano using Goodman's perspective from Chapter Five. Similar to these two perspectives, those Meccanomen in both groups also based their answers on personal experiences, further demonstrating that Kroto's perspective was an equivalent personal perspective composed of his experiences of working in the field of chemistry and being part of the 'golden age' first generation of Meccanomen.

5. The 'Golden Age' of British Engineering

This section focuses on the question, 'Was there a 'golden age' of British engineering, and were you a part of it?' The purpose of this question was to see if the Meccanomen co-located the 'golden ages' of Meccano and British engineering in the same way as the conventional public history of Meccano. Among the respondents, 76% agreed that there had been a 'golden age' of British engineering, although only 42% believed that they were a part of it. Taken in conjunction with the previous section (in which 67% believed that they had lived through the 'golden age' of Meccano), these figures suggest that the majority of the Meccanomen in the sample do not co-locate the 'golden ages' of Meccano and British engineering.

James Davies was an example of a Meccanoman who did not co-locate the 'golden age' of Meccano with the 'golden age' of British engineering. Instead, he told me that the 'golden age' of British engineering had ended '…after the merging of three locomotive builders – Sharp Stewart and Company, Neilson, Reid and Company, and Dübs and Company – into the North British Locomotive Company in 1903.' He explained that this merger had decreased the competition between these companies and allowed overseas companies to '…innovate and eventually surpass Britain's world-leading position.' I then asked him to tell me about his first experiences with Meccano to see if there was a correlation between his initial interaction with the hobby and his view of the 'golden age' British engineering. He told me that his 'Mum bought [him] a No. 2 outfit in 1946 at a Bentall's department store in Kingston,' which he used to replicate the small locomotives that featured in *Meccano Magazine* as part of the section 'Railway News.'[601] While his answer does not fit with the

[601] James Davies, personal interview, 15 April 2017.

conventional public history of Meccano, the correlation between his answers suggested a grouping of those who co-located the 'golden age' of British engineering with their initial Meccano experiences.

Similar to Davies, Edward Olsen also composed a set of answers that did not fit with the conventional public history of Meccano but fit in this group. Instead of the linking the 'golden age' of British engineering to the locomotives, Olsen asserted that it was in the 1920s 'due to the heavy industry in Britain around bridges and cranes, which declined after the Second World War, as an increased emphasis began to be put on electronics and computers.' When I pushed him on his first experiences of Meccano, he explained that it had been when 'My father bought me a set in 1953 for Christmas, which came with a crane and bridge instruction manual that captured my interest and still dominates my crane obsession.' He then told me that for the rest of his childhood birthdays and Christmases, he asked for '…bits to add to my No. 3 set…which allowed me to graduate to a No. 7 outfit that meant I could begin to build much bigger cranes.'[602] While Olsen's responses share a similar correlation to Davies', the difference in their perspective of when the 'golden age' of British engineering was, helps to demonstrate the lack of consensus among the Meccanomen on this issue.

Jim Gaines asserted that the 'golden age' of British engineering was 'when Britain made cars…companies such as Rolls Royce and Aston Martin are the remnants of this.' He told me his first experience with Meccano had been with a second-hand set that he received from his brother, which started his 'life-long love of the toy' and helped him 'develop the skills that he now uses in [his] career restoring classic cars.'[603] His answers placed him in the same group as Davies and Olsen. What was interesting is that despite members correlating their

[602] Edward Olsen, personal interview, 3 September 2017.
[603] Jim Gaines, personal interview, 17 October 2016.

view of the 'golden age' of British engineering with their childhood experiences with Meccano, there were none that co-located of British engineering with the conventional 'golden age' of Meccano in the 1930s.

Alongside these Meccanomen were another group that did co-locate these two 'golden ages,' but placed them at a different time to what was described in the conventional public history. Tom Morton responded that both Meccano and British engineering industry peaked and declined during the 1950s and 1960s, '…when the Meccano Mag was on sale in every newsagent, [and] there was no end to things that you could do.' However, while he co-located the 'golden ages' of Meccano and British engineering, he did not situate them in the 1930s. When I asked about his first experience with Meccano, he told me it was in 'the late 1950s, around the time I sat my 11+ exam for grammar school.' He explained that after he failed this exam, he spent the summer building a Meccanograph that he took to school and showed his headmaster. He told me that his headmaster had been so impressed with the Meccanograph that he insisted Morton retake the 11+ exam, which he passed. Morton then told me that that experience with Meccano had led him to attend grammar school and university where he 'studied physics at undergraduate and mathematics at a postgraduate level, before becoming a professional engineer.'[604] His responses were interesting as despite being part of a separate group of Meccanomen who did co-locate the 'golden ages' of Meccano and British engineering, the correlation between his answers and personal experiences were similar to the Davies, Olsen, and Gaines above.

During the second half of the interview, I challenged Morton's co-location in the 1950s by explaining the conventional public history of Meccano that co-located them in the 1930s.

[604] Tom Morton, personal interview, 19 April 2017.

He disagreed with this co-location, saying that Meccano had ‘changed the course of my life…you know, without it, I would have gone to a less good school, and not got a degree or became an engineer.’ He paused for a few seconds and then said ‘…however, my experience doesn’t translate to other members, so they will have a different view.’ Morton’s answers represented a historical alternative to – and a historiographical critique of – the conventional public history of Meccano. While he co-located the ‘golden ages’ of Meccano and British engineering in the 1950s instead of the 1930s, he was also aware that co-location was not an effective way to describe the experiences of his peers. The other members of this group similarly explained that while they co-located the ‘golden ages’ of Meccano and British engineering at various times in the twentieth century, they did not believe that their perspective was shared or could be generalised to the wider Meccanomen membership. Therefore, the majority of Meccanomen who believe that there was a ‘golden age’ of British engineering do not believe they were part of it. The main reason for their deviation from the conventional public history of Meccano was that the majority composed their perspectives based on their initial personal experiences with Meccano. Some of their responses also offered a historiographical critique of how the conventional public history of Meccano has tended to treat the Meccanomen as a group who have had homogenous experiences and share the same perspectives on their hobby.

6. Meccano and the Popular Belief in a British Decline

This section considers the responses to the following question, 'Do you think that Britain has declined, and do you think that if more young people used Meccano today, it would reverse this?'[605] This question was designed to test whether the Meccanomen subscribed to a popular belief in British decline and if they correlated it with the conventional perspective that the demise in popularity of Meccano led to a decline in British engineering. Among those interviewed, 82% answered positively, demonstrating that the majority do subscribe to the idea of the popular declinist thesis. However, as the following analysis will demonstrate, there was no consensus among the Meccanomen as to what this British decline was, and if it correlated with Meccano. The 82% was comprised of three main groups, with the largest claiming that the decline was skills-based, who broadly believed that an increase in Meccano would reverse it. The next largest group asserted that this decline related to the morality of the younger generation and that an increase in Meccano would not reverse it. The third group was comprised of those who asserted that Meccano became outdated due to changes in society caused by the development of computers, rather than the idea of a British decline caused by the demise of Meccano. There was also a fourth grouping of Meccanomen, comprised of those who critiqued the historical concepts of 'golden ages' and decline as they have been applied in the conventional public history of Meccano. This section also extensively includes voices from the OHBS archives, as the issue of a decline in British science and engineering was a prominent theme in many of their interviews.

An example from the first group was Richard Hudson, who asserted that 'Britain was better when children got training to use their imagination and develop the practical building

[605] Note that the questions did not specify what was meant by 'the national good.' This was initially left open for the interpretation intentionally, to allow the Meccanomen to compose their answers.

skills…the toys they have today don't do this.'[606] Similar to Hudson, Frederick Woodgate told me that 'A good grounding in the real world and what makes it work physically has got to be a good thing, and that is what Meccano offered. There is a danger that the new generations are losing touch with reality…witness the way they are living their lives through social media, selfies, and all that nonsense.'[607] While these Meccanomen alluded to a skills-based decline, they did not explicitly state that an increase in the popularity of Meccano would be beneficial. However, there were also those Meccanomen in this group who agreed that an increase in Meccano would reverse this decline. One of these was Frank Marsh, who told me that 'Yes, an increase in Meccano would be good as it would help improve children's retention and attention span on more complex issues.'[608] Brian Mayes's response was similar, as he stated that 'YES. Meccano would encourage more children to become engineers, but Lego has a stranglehold at an early age. An increase [in Meccano] would improve the engineering and industrial prospects of the country.'[609] Despite their differences of opinion on whether a return to Meccano would be beneficial, the majority of this group believed that Meccano had been crucial for the creation of British engineers in the past, with Ballard asserting that 'I've heard stories of mechanical engineers today who have never used a spanner…so where is their knowledge and experience?'[610]

This grouping was also prevalent in the OHBS archives, with Robert Maguire (Architect) stating that it is 'difficult to find things [in the present day] that encourage creativity as much as [Meccano].' He then criticised more modern toys as things that go too far in making everything too easy for children, as there is no need to 'carve anything or make

[606] Richard Hudson, personal interview, 18 April 2018.
[607] Frederick Woodgate, personal interview, 17 October 2017.
[608] Frank Marsh, personal interview, 16 April 2017.
[609] Brian Mayes, personal interview, 17 November 2016; and Colin Gray, personal interview, 16 October 2016.
[610] Peter Ballard, personal interview, 17 October 2016.

anything.'[611] Alongside Maguire was Alan Smith (Geologist), who explained that his father saw him as a 'future engineer' and so made sure to give him 'a wonderful Meccano set,' and Bob Parkinson (Aeronautical Engineer) who stated that Meccano was 'brilliant as a budding engineer' as it taught him to 'think in terms of building things, making things, and doing things, which is missing today.'[612] While these perspectives do not directly correlate Meccano with a decrease in skills in the UK, they imply a deficit in the skills of those who did not grow up with Meccano.

Similar to these perspectives was Mike Kay (various roles at NORWEB, later Electricity North West), who more directly claimed that the demise of Meccano had led to fewer engineers being produced, saying that 'Lego eventually undercut the age of Meccano users – and got them hooked onto Lego before the 'older' Meccano could be experienced.' However, what is interesting about Kay's perspective compared to the other voices in the OHBS archive is that as well as alluding to a skills-based decline, he also invoked elements of a moral decline. He did this by asserting that because 'Lego was easy to put together,' children who used it could also be defined by their 'laziness.'[613] Nevertheless, the Meccanomen and OHBS enthusiasts that fell into this particular group tended to agree with the conventional public history of Meccano, believing that there had been a decline in engineering skills as a result of the demise of Meccano and that an increase in popularity would be beneficial.

The notion of a moral decline that Kay alluded to also defined the perspectives of those placed into the second group. For those Meccanomen who believed in a moral decline,

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[611] Robert Maguire, interviewed by Linda Sandino, 2004, C467/79, https://sounds.bl.uk/Oral-history/Architects-Lives/021M-C0467X0079XX-0001V0 [accessed 20 October 2016].

[612] Alan Smith, interviewed by Paul Merchant, 16 December 2011, C1379/65, https://sounds.bl.uk/Oral-history/Science/021M-C1379X0065XX-0001V0 [accessed 21 October 2016]; and Bob Parkinson, interviewed by Thomas Lean, 2 October 2010, C1379/05, https://sounds.bl.uk/Oral-history/Science/021M-C1379X0005XX-0001V0 [accessed 20 October 2016].

[613] Mike Kay, interviewed by Thomas Lean, 2 October 2015, C1495/44, https://sounds.bl.uk/Oral-history/Industry-water-steel-and-energy/021M-C1495X0044XX-0001V0 [accessed 20 October 2016].

their perspectives contrasted to the conventional public history of Meccano, which asserts that there has been a decline in British engineering skills and that a return to Meccano would resolve it. This was the biggest difference between this group and the previous one, which subscribed to the idea of a skills-based decline. While most members in the first group believed that an increase in popularity would reverse the decline they perceived, those in the second who believed there had been a moral decline did not think it would be reversed by reintroducing Meccano. These groups highlight that there was no consensus on the type of decline in the younger generation among those interviewed

Stuart Martyn was an example of this second group, telling me that 'young people need help to be more creative, patient, innovative, and imaginative like I was at a young age.' When I asked him if he thought that Meccano could solve this problem, he said 'No, because society has moved on.'[614] Pete Charlton had a similar perspective, telling me, 'Look, I'm no politician and never will be, but they [young people] need a solid foundation below them…Their attitudes and morals need far more of a makeover than anything else at the moment! I'll stop there!' When I pushed Charlton on the idea that Meccano was the solution to this, he disagreed, stating 'no, while the demise of Meccano may have started the process, it can't explain how bad it has all gotten today.'[615] This perspective was also shared by Stanley Hart, who said that 'Yes, an increase in Meccano would have been great 30 years ago, but is too little too late now for this generation.'[616] What was interesting about this second group was that while they all tended to agree that the moral decline had begun as a result of the demise of Meccano – in line with the conventional public history – all but one agreed that it would not be sufficient to undo the problems they now saw in the younger generation today.

[614] Stuart Martyn, personal interview, 16 October 2017.
[615] Pete Charlton, personal interview, 24 October 2016.
[616] Stanley Hart, personal interview, 16 October 2017.

The only alternative perspective in this group was Roger Aarons, who believed in both a moral decline and asserted that if the availability and use of Meccano increased '…it would improve engineering skills, and encourage self-help amongst the young' draws from elements of both of these groups.[617] His allusion to self-help was reminiscent of Samuel Smiles' book of the same name that had encouraged Victorian boys to follow the example of learned men and improve themselves and was believed to have inspired Frank Hornby's original patent for Meccano in 1901.[618] Aaron's perspective that the value of Meccano lay in its usefulness as a tool for self-improvement – rather than simply improving the industry and economy – was made clearer when I emailed him a few months after we spoke to clarify some of his responses. When I asked him if a return to Meccano would be beneficial for Britain, he responded that 'Yes! Young people who create do better later in life…they do not vandalise'[619]

The third group that emerged was comprised of those who believed that there had been a change in Britain, but they did not associate it with a skills-based or moral decline of the younger generation or the demise in Meccano. Instead, this group suggested that the demise of Meccano was a symptom of wider technological advancement, rather than a factor in Britain's decline. Raymond Edwards's perspective was that 'I think there is still a lot of engineering still going on, but there has been lots of change, which has moved us away from physical Meccano to focus more on things like software engineering.'[620] Similar to Edwards, Aiden Barnes' perspective was that the demise of Meccano was a symptom of a move in the economy towards more service-based activities, rather than a direct cause of an engineering decline. He explained that 'we produce very little physically…ideas are sold today, but not

[617] Roger Aarons, personal interview, 17 November 2016.
[618] Patent No. 587-1901, F. Hornby, 'Improvements in Toy or Educational Devices for Children and Young People,' (9 January, 1901), pp. 1-4.
[619] Roger Aarons, personal interview, 17 November 2016.
[620] Raymond Edwards, personal interview, 17 October 2017.

things, and Meccano is only good for making things.'[621] Other responses that demonstrate this lack of consensus include William Alexander, who simply stated 'NO!,' and David Hodges, who asserted that 'No, we are now in a Computer age. Meccano did not put a Man on the Moon, a computer program did.'[622] Dai Vaughan's response went further, divorcing Meccano entirely from contemporary British industry and society and describing it as a 'product and tool of the past,' He stated that while 'Lego is far too simplistic, it has been more successful than Meccano because of better marketing to parents…Meccano is now an 'old mans' hobby.'[623] Alongside the views of this group, Stephen Paul asserted that:

> I have done a lot of work with young people and can confirm that we are not 'evolving backwards' in any fashion and that youngsters today are every bit as smart as we Meccanomen were in our youth. Today's youngsters simply choose to exploit and exhibit their human intellect in other directions – and good luck to them.[624]

The variety of perspectives among these three groups demonstrate that despite 82% of the Meccanomen agreeing with the question, there was no consensus that the British decline they believed in was related to engineering skills, or whether a return to Meccano would be beneficial to resolve it. While the majority of voices from the OHBS archives did support the conventional public history of Meccano on the idea of a decline in British engineering skills, there were still examples of those who disagreed. Steve Furber (Computer Scientist) states that 'Meccano was good up to a point, [but] it was not quite precisely enough made for everything to work the way you expected it to…you had to make large sacrifices for

[621] Aiden Barnes, personal interview, 3 September 2017.
[622] William Alexander, personal interview, 8 October 2016; and David Hodges, personal interview, 17 April 2017.
[623] Dai Vaughan, personal interview, 18 September 2017.
[624] Stephen Paul, personal interview, 11 September 2017.

its mechanical tolerances to get things to work.'[625] His response helps to demonstrate that the answers given in my interviews were not just the result of my unusual participatory approach. Instead, his words suggest that these non-conventional views have always existed but have not previously been interpreted or facilitated to be expressed in previous histories of Meccano and decline.

There was also a fourth group of answers to this question, comprised of Meccanomen who critiqued how the concepts of 'golden ages' and British decline had been used to describe Meccano. Jeremy Osbourne told me that '…nostalgia is a big business that becomes self-fulfilling, because the things which we are nostalgic about are not with us anymore…this is what has happened with Meccano.'[626] His view of the past incorporated its negative aspects, with him saying that 'While I think the ability to look backwards is itself a pleasure…I look back fondly at my first car - but it was bloody awful.'[627] Noel Lyne shared Osbourne's cynical view of nostalgia and British decline, stating that:

> While there are many things about the good old days that I would like a return to, my memories of the late sixties/early seventies are mixed…I remember being cold, hungry, and wearing hand-me-down clothes. I remember power cuts, sharing a bath with my brothers, just three channels on TV, and as a young adult, paying a 15% mortgage.[628]

[625] Steve Furber, interviewed by Thomas Lean, 11 June 2012, C1379/78, https://sounds.bl.uk/Oral-history/Science/021M-C1379X0078XX-0001V0 [accessed 20 October 2016].
[626] Jeremy Osbourne, personal interview, 19 August 2017.
[627] Jeremy Osbourne, personal interview, 19 August 2017.
[628] Noel Lyne, personal interview, 15 April 2017.

When I asked Lyne if he had a nostalgia for the past and Meccano specifically, he told me, ‘No, I would choose today over the good old days every time!’[629] Similar to Lyne, Tony Manning responded to the question of whether a return to Meccano would be beneficial, with the following critique of both the ‘golden age’ of Meccano and the popular belief in a British decline:

> No, even in the “good old days” most youngsters found Meccano difficult and didn't make anything other than elementary models. The few who benefited mostly didn't need Meccano as a spur to their ambitions or skills…the same is true today. Instead, my advice would be to get a good grounding in computer technology.[630]

The use of quotation marks around his phrase “good old days” is to represent the air quotes that Manning made with his fingers when he gave me this answer. When I pushed him on what precisely he meant with these air quotes, he responded, ‘Look, I love Meccano, but the “golden age” you have suggested is a fiction.’ When I then told him that the idea of the ‘golden age’ has continued to be a prominent feature of the ‘alternative’ version of Meccano since it was established in 1965, he shook his head and said I needed to:

> Ignore what has been written in books and journals…the reality is that [Meccano] was not a tool that helped to make engineers, [but] merely a playful toy that was important for some in their youth…any member will tell you that all it did was expose them to ideas and mechanical concepts that they would have not otherwise experienced.[631]

[629] Noel Lyne, personal interview, 15 April 2017.
[630] Tony Manning, personal interview, 17 October 2016.
[631] Tony Manning, personal interview, 17 October 2016.

Manning's response critiqued both the conventional public history of Meccano and took issue with the concepts of 'golden age' and decline as tools to explain changes in Britain and Meccano. The perspectives of those in this fourth group were interesting as their critiques of these concepts of declinism echo those made by historians Edgerton, Tomlinson, and others that were explored in the second section.[632]

While the majority of Meccanomen and OHBS enthusiasts agreed that there had been a decline in Britain, there was no consensus as to what this decline was, with the majority of this group disagreeing that an increase in Meccano would reverse the decline they perceived. The three main groups tended to be comprised of those who believed that there had been a skills-based decline that Meccano could resolve, those respondents for whom this decline was moral in nature and that Meccano could not resolve, and those who believed that the demise of Meccano was a symptom of British development in computing and other sectors, rather than a factor of decline. It also demonstrated that the majority of OHBS voices also fit into the first group, but that there were also examples of those who also fit into the other groups. This helped to demonstrate that Meccanomen outside of my specific interview approach also composed views that do not fit with the conventional public history of Meccano. The final part of the section established that there was also a fourth group, containing those who composed participant historiographies that critiqued the concepts of 'golden age' and decline.

[632] B. Collins and K. Robbins (eds.), *British Culture and Economic Decline* (London, 1990); D. Edgerton, '*Science, Technology, and the British Industrial 'Decline,' 1870-1970*' (Cambridge University Press, 1996); J. Tomlinson, *The Politics of Decline: Understanding Post-War Britain* (Pearson, 2001); and A. Sampson, *Who Runs This Place? The Anatomy of Britain in the 21st Century* (Hodder and Stoughton, 2004).

7. Conclusion

The chapter has demonstrated that when given the opportunity, the Meccanomen composed histories and participant historiographies that did not fit with the conventional public history of Meccano, without experiencing discomposure. The voices of the Meccanomen and the enthusiasts from the OHBS archives built on Matt Goodman's perspective from the previous chapter, indicating that the majority interviewed composed responses based on their personal experiences. The personal nature of their responses helps to explain why they did not experience discomposure when giving responses that did not fit with the conventional public history of the International Society of Meccanomen. Another reason may be that despite intentionally designing the interview questions to situate them as representatives of the Meccanomen movement, they did not see their roles in the same way. The previous chapters in this thesis hint at reasons why they did not see themselves primarily as part of the Meccanomen movement and why they deviated from fulfilling the roles and cultural narratives that I intended them to fulfil.

Both Chapter One and Chapter Five established the non-homogenous nature of Meccano clubs and their users, and how members have expressed individual agency and continuously reshaped their hobby since 1901. This context, taken with the fact that so few experienced discomposure when giving answers that did not fit with the conventional public history of the role assigned to them suggests that they may have viewed their roles in the interview as individual Meccano hobbyists first, representatives of their clubs second, and members of the International Society of Meccanomen third. This layering of identity may also explain the differences between their answers on British decline and Meccano and those from the OHBS archive. In contrast to the Meccanomen, the OHBS respondents – given identities in their interviews as 'leading UK scientists and engineers' – may have felt obliged to compose their answers to reflect their status as members of the 'Great British Scientific Establishment.' However, this idea of personal identity is no more than a tentative explanation for why there appeared to be no broad consensus among the Meccanomen's responses on the issues of 'golden ages' and a popular belief in British decline. Further research and analysis would be needed to understand better why they did not appear to experience discomposure in this interview context.

While being initially unsure about the decision to collect oral testimonies in a way that also encouraged participants to co-curate participant historiographies, the fact that so many Meccanomen used their interview to critique how their hobby has been written about previously demonstrates that this participatory approach was useful in co-curating a new historiography of Meccano. This was because it provided a space where the Meccanomen could express a much richer, diverse, and complex set of perspectives on the issue of 'golden ages' and their belief in a British decline, compared to if the interviews had simply tested the accuracy of their recall on issues relating to the conventional public history of Meccano. Instead, it provided them with a space to express how they felt about the historiography of Meccano, which led to a series of responses that were both much richer than the 'mainstream' and 'alternative' versions of Meccano, and existing conventional public history of Meccano. The experience of working with the Meccanomen using 'shared authority' inspired me to collaborate with them to create a working model differential analyser from Meccano and cultivate its public history. Chapter Seven explores this collaboration to reconstruct the Kent machine, and discusses the challenges and opportunities of constructing its public history in contrast to the Trainbox in the Science Museum.

Chapter Seven – Tacit Knowledge, Historical Fidelity, and Public Engagement: Exploring the Reconstruction of the Kent machine

1. Introduction

The previous chapters in this thesis have told the stories of Meccano and original differential analyser as two parallel and intersecting stories. This chapter aims to unite these threads by telling the story of how I worked to historically reproduce the original differential analyser as the Kent machine. I have deliberately used the word 'reproduce' throughout the chapter, instead of 'reconstruct,' 'rebuild,' or 'recreate,' to emphasise that the Kent machine was designed as a historical reproduction that had a high level of historical fidelity to the materials, design, and instrumentality of the original differential analyser.[633] The method of historical reproduction was used to learn more about the original differential analyser than what features in textual sources. The Kent machine did this by allowing me to explore the hands-on challenges that Hartree and Porter faced when they built the analyser, and recover some aspects of the tacit and gestural knowledge that they used to overcome these problems. This approach also provided the opportunity to create a public history for the Kent machine that differed from the ventriloquised one attached to the Trainbox object on display in the Science Museum. As the public history of the Kent machine was developed using 'shared authority,' the chapter also considers the conflicts of authority that arose as with my collaborators, Ian Henwood and Matt Goodman (members of the International Society of

[633] The term 'reproduce' and the reasons for its use features in H. Fors, L. M. Principe, and H. O. Sibum, 'From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science,' *Ambix*, Vol. 63 (2), (2016), p. 94.

Meccanomen), Bonita Lawrence (Professor of Mathematics at Marshall University, WV), and the different audiences that viewed the Kent machine.[634]

The second section briefly discusses how tacit knowledge has developed from a single concept to one comprised of different incremental stages. It then outlines what types of tacit knowledge I believed reproducing the Kent machine would recover, and how my approach compared with previous attempts to historically reproduce scientific experiments and objects.[635] It then explores two examples of the tacit and gestural knowledge that the Kent machine helped to recover and considers their historiographical importance, both to my thesis and more generally for future historical reproductions.

The third section introduces the concept of historical fidelity and describes how maintaining (and ignoring) aspects of the design, materials, and instrumentality of the original differential analyser impacted the exploration of the Hartree and Porter's tacit and gestural knowledge.[636] It discusses three occasions when we were required to decide whether or not to maintain historical fidelity, and the improvised solutions used to 'infill' these gaps in our approach. It uses them to highlight that the challenge of maintaining historical fidelity to the original differential analyser helped us to inadvertently access some aspects of tacit knowledge, which we may not have been able to recover had we maintained as much fidelity as possible.

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[634] M. Frisch, *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (University of New York Press, 1990), p. xxiii; and T. Cauvin, *Public History: A Textbook of Practice* (Routledge, 2016), p. 12.
[635] Historical studies of experimental practice feature in S. Shapin, and S. Schaffer, *Leviathan and the Air-Pump* (Princeton University Press, 1985); P. Galison, *How Experiments End* (University of Chicago Press, 1987); and Gooding, Pinch, and Schaffer's *The Uses of Experiment* (Cambridge University Press, 1989). The main examples used in this research include H. O. Sibum, 'Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England,' *Studies in History and Philosophy of Science Part A,* Vol. 26 (1), (1995), pp. 73-106; and M. Usselman, A. Rocke, C. Reinhart, and K. Foulser, 'Restaging Liebig: A Study in the Replication of Experiments,' *Annals of Science*, Vol. 62 (2005), pp. 1-55.
[636] P. Heering, 'The Replication of the Torsion Balance Experiment,' *American Journal of Physics*, Vol. 60 (11), (1992), pp. 988-994; and H. Fors, L. M. Principe, and H. O. Sibum, 'From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science,' *Ambix*, Vol. 63 (2), (2016), pp. 85-97.

The fourth section of the chapter explores the challenges of 'shared authority' that I experienced when using the Kent machine as a public engagement object to teach different audiences about historical reproductions and the history of differential analysis. Through this exploration, it attempts to answers Jordanova's question on public history of 'who may speak with authority about the past, and by virtue of what qualities?'[637] It also considers the ways that audiences at demonstrations in the UK and USA helped to change the public history of the Kent machine based on their 'shared authority.' It concludes by exploring how I have worked to ensure that this complex public history is retained once the machine is collected and displayed by the Science Museum.[638]

Throughout the chapter, the words 'our' and 'we' to refer to the series of collaborators who were crucial in helping this project get off the ground. These include two members of the International Society of Meccanomen, Ian Henwood and Matt Goodman; a Professor of Mathematics from Marshall University, Bonita Lawrence; a student volunteer, Rachel Crawford; two supervisors, Ben Russell (Curator of Mechanical Engineering at the Science Museum) and Charlotte Sleigh (Professor of Science Humanities at the University of Kent); and the Special Collections and Archives Manager at the Templeman Library, Karen Brayshaw. Without them (and others), the Kent machine would still be a big pile of Meccano pieces (see figure 7.1).

[637] L. Jordanova, 'Public History,' *History Today*, Vol. 50 (5), (May, 2000).
[638] For more information on 'Re-Engineering History' event (October 8th-11th) and 'Playful Engineering' demonstration (October 9th), refer to: https://blogs.kent.ac.uk/sci-ex/2018/10/04/re-engineering-history-a-playful-demonstration/ and https://blogs.kent.ac.uk/specialcollections/2018/10/05/re-engineering-history-a-playful-demonstration/ [accessed 10 October 2018].

Figure 7.1: An image is of Ian Henwood (L) and Matt Goodman (R) with the reproduced Kent machine on 8 October 2018. (Image taken by author).

2. Tacit Knowledge

Tacit knowledge is the name given to something a person knows, but cannot easily explain or teach to others. An everyday example of tacit knowledge is how we use language to create meanings in our conversations with others. When speaking and understanding a particular language, we rely on a specific set of rules; however, we would have difficulty writing these rules down and explaining them to others, due to our knowledge of them being tacit rather than explicit. For instance, we are told the mnemonic rule at school that 'I comes before E, except after C,' without ever explicitly being told that there are only 44 examples that do (and 923 examples that do not) support this rule in the English language. Despite this, we know that Ph.D. students are a spe**cie**s that are grateful to re**cei**ve caf**fei**ne. This ability to understand when 'I' does or does not come before 'E' is an example of what Michael Polanyi first called 'personal' or 'tacit knowledge' of the English language, which we increase through our experiences and engagement with it.[639] Mary Jo Nye's analysis of Polanyi's earliest ideas of 'tacit knowledge' describes how they answered a desire for a more sociological approach to science in the context of a post-war Europe, and that he based his early work on Wittgenstein's paradox that knowing something does not account for how we came to know it.[640]

Hubert Dreyfus developed Polanyi's concept of tacit knowledge with his 'model of skill acquisition,' which attempted to explain how skills were learned by breaking tacit knowledge into different levels of knowledge that require different processes to learn (see figure 7.2).

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[639] M. Polanyi, *Personal Knowledge: Towards a Post-Critical Philosophy* (Routledge and Kegan Paul, 1958); and F. Schwartz (ed.), *Scientific Thought and Social Reality: Essays by Michael Polanyi* (International Universities Press, 1974).
[640] M. J. Nye, *Michael Polanyi and His Generation: Origins of the Social Construction of Science* (University of Chicago Press, 2011), pp. 1-37.

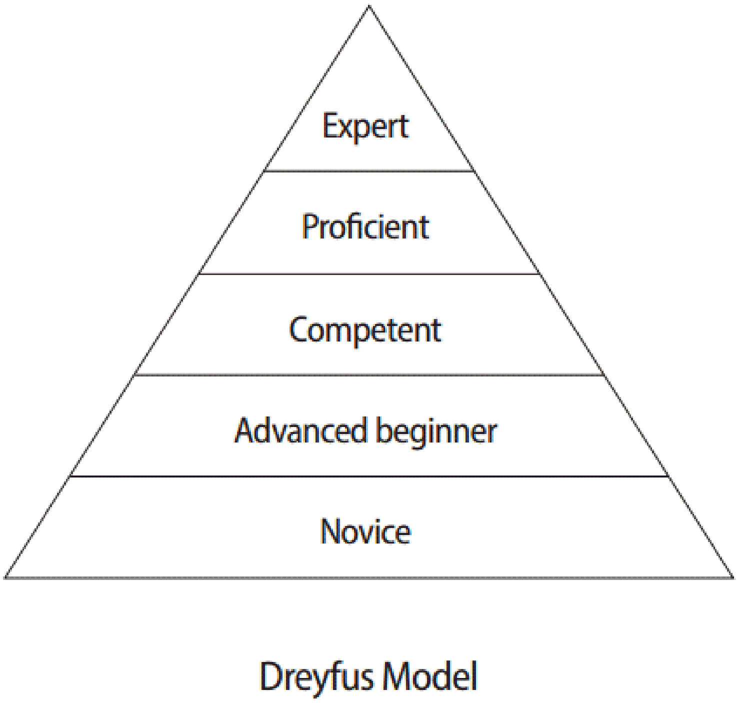

Figure 7.2: An image of Dreyfus's pyramid model of skill acquisition, developed based on Polanyi's concept of tacit knowledge. (Image reproduced from J. Park, 'Proposal for a Modified Dreyfus and Miller Model with Simplified Competency Level Descriptions for Performing Self-rated Surveys,' *Journal of Educational Evaluation for Health Professions*, (2015)).

Dreyfus's model argues that knowledge and expertise are distinguished by their need to be based on intuition (something that he argued a computer could never possess), rather than on a set of explicit rules (that a novice relies on).[641] However, it is hard to apply the Dreyfus model to the Kent machine project, as the former was designed to critique the development of artificial intelligence machines, while the latter aimed to recover the tacit knowledge of Hartree and Porter. Therefore, instead of using Dreyfus's model to understand the tacit and gestural knowledge recovered with the Kent machine, this chapter relies more on Polanyi's belief that '…knowledge is either tacit or rooted in tacit knowledge,' and therefore is not a logical, rule-driven, or explicitly knowable process.[642]

[641] The model was first proposed in S. E. Dreyfus, and H. L. Dreyfus, 'A Five-Stage Model of the Mental Activities Involved in Directed Skill Acquisition,' *Operations Research Centre*, (University of California, 1980), pp. 1-18.
[642] M. Polanyi, *Personal Knowledge: Towards a Post-Critical Philosophy* (Routledge and Kegan Paul, 1958), pp. 90-91; and M. Polanyi, *The Tacit Dimension* (University of Chicago Press, 1966), p. 195.

Harry Collins and Robert Evans' *Rethinking Expertise* (2007) created a compromise between Polanyi's approach and the Dreyfus model by creating a 'Periodic Table of Expertises' to explain tacit knowledge. Collins and Evans split Polanyi's general concept of tacit knowledge into five stages of 'ubiquitous' and 'specialist' tacit knowledge, which they believed related to different levels of expertise (see figure 7.3).[643] In contrast to Dreyfus's belief that tacit knowledge exists within an individual, Collins and Evans locate it as something that exists within society. Using language as their example, they argue that all individuals draw upon this 'collective tacit knowledge' to develop their tacit knowledge. They assert that we only learn the tacit knowledge required for language by immersing ourselves in a society that collectively speaks and shapes it, progressing through the five stages they set out.[644]

PERIODIC TABLE OF EXPERTISES

UBIQUITOUS EXPERTISES					
DISPOSITIONS	Interactive Ability Reflective Ability				
SPECIALIST EXPERTISES	***UBIQUITOUS TACIT Knowledge***			***SPECIALIST TACIT Knowledge***	
	Beer-mat Knowledge	Popular Understanding	Primary Source Knowledge	Interactional Expertise	Contributory Expertise
META-EXPERTISES	***EXTERNAL***		***INTERNAL***		
	Ubiquitous Discrimination	Local Discrimination	Technical Connoisseurship	Downward Discrimination	Referred Expertise
META-CRITERIA	Credentials	Experience	Track-Record		

Figure 7.3: An image of Collins and Evans's periodic table of expertises, demonstrating specialist expertises and ubiquitous and specialist tacit knowledge. (Image reproduced from H. Collins and R. Evans, *Rethinking Expertise* (University of Chicago Press, 2000)).

[643] For more detail on the three stages of ubiquitous tacit knowledge, refer to H. Collins, and R. Evans, *Rethinking Expertise* (University of Chicago Press, 2007), pp. 14-18.

[644] H. Collins and R. Evans, *Rethinking Expertise* (University of Chicago Press, 2007), p. 15.

Using Collins and Evans's model, the previous chapters in this thesis have relied on my ubiquitous tacit knowledge of my subject matter, based on a popular understanding of Meccano and primary source knowledge of the original differential analyser. In contrast, this chapter aims to recover what they describe as specialist tacit knowledge of both Meccano (through developing my 'interactional expertise' of building models) and the original differential analyser (though increasing my 'contributory expertise' about how it was constructed and functioned). Therefore, in preparation to develop my contributory expertise of the original differential analyser, I sought to develop my interactional expertise of its mathematical functions and how it could have been built from Meccano. Collins and Evans explain that to develop interactional expertise, one must engage in conversation with experts and become enculturated into their communities.[645]

To begin this process of developing my interactional expertise, I engaged with Bonita Lawrence at Marshall University, who explained the mathematics of a differential analyser using her reconstructed differential analyser.[646] I also collaborated with the Meccanomen, whose experience of building large working models or real-world machines from Meccano was something that would benefit the historical reproduction of the Kent machine. While these interactions increased my interactional expertise of the original differential analyser, they would not help me to recover the contributory expertise that Hartree and Porter had used to build and use their original object. This was because recovering this contributory knowledge required me to directly engage with the processes of building and operating a differential analyser from Meccano. Therefore, despite numerous visits to the Meccanomen

[645] Ibid., p. 28.
[646] Bonita's machine, 'ART' was constructed in 2007. It is a Meccano differential analyser that she and her team built with the help of Arthur Porter.

clubs, and demonstrations of Bonita's machine over FaceTime, I was aware that I was no closer to being able to access and recover this contributory expertise.

At this early stage of the project, I asked myself, 'why should a historian of science try to recover tacit knowledge of an object?' The answer to this question depends on what value we believe is gained from attempting to recover tacit knowledge through historical reproductions. Otto Sibum's research on James Joule's paddle-wheel experiment serves as an example of the value provided by historical reproductions, and helps to explain my failure in recovering this contributory expertise by simply having discussions with Bonita and the Meccanomen. His work on historically reproducing Joule's experiment helps to define tacit knowledge as dimensions of past practices that have been taken for granted, hidden, or not documented.[647] Sibum blames his failure to replicate Joule's experiment on what he describes as Joule's 'relevant artisanal' skills as a brewer, which did not feature in previous textual sources. He asserts that his struggles in recreating the experiment in 'On the Mechanical Equivalent of Heat' revealed what he believed to be a specific type of tacit knowledge – 'gestural knowledge' – that could only be recovered through reproducing experiments. He concludes that this was crucial to Joule's success, as they gave him an 'embodied capacity…a particular gestural knowledge [that] was incommunicable.'[648]

Therefore, successfully reproducing the original differential analyser required recovering both Hartree and Porter's contributory expertise of how to build and operate the original differential analyser, and the gestural knowledge of how to construct it from Meccano. Critics of Sibum and other proponents of historical reproductions believe that they indulge in a type of positivist history, and that their reproductions reveal more about the

[647] H. O. Sibum, 'Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England,' *Studies in History and Philosophy of Science Part A,* Vol. 26 (1), (1995), p. 76.
[648] Ibid., p. 103.

historian than the original experimenter. This chapter counters these criticisms by building on Sibum's work, through analysing the effect of Ian's improvisation on the reproduction. It also acknowledges that the Kent machine cannot replace the more traditional textual sources on the original differential analyser and openly discusses the effect that the processes of reproduction had on me as a historian. It also describes the efforts made to cultivate a 'good' public history of the Kent Machine that focused on telling the deconstructed stories of Hartree and Porter's original Meccano differential analyser from the earlier chapters in this thesis. The rest of this section discusses two examples of tacit knowledge (both contributory expertise and gestural knowledge) that were recovered with the reproduction of the Kent machine. It also evaluates their historiographical significance and how they enhance the knowledge of the original machine beyond what features in textual sources.

When I set out to reproduce the original differential analyser, I found two Meccano differential analysers that had been built since 2005, belonging to Tim Robinson in California and Bonita in West Virginia (see figure 7.4a and 7.4b). Despite both being inspired by the same Trainbox object in the Science Museum, their machines were not designed as historical reproductions of the original differential analyser, but rather as contemporary explorations of the mathematical principles of integration. Tim and Bonita both told me that they had built their analysers with the advice, support, and [tacit] knowledge of Arthur Porter.[649] My conversations with Bonita revealed that her team had decided against using the torque amplifiers from the original differential analyser, in favour of using servomechanisms on their

[649] C. Brooks, S. Keshavarian, B. A. Lawrence, and R. Merritt, 'The Marshall Differential Analyser Project: A Visual Interpretation of Dynamic Equations,' *Advances in Dynamical Systems and Applications*, Vol. 3 (1), (2008), pp. 29-39; and 'Tim Robinson's Differential Analyser,' http://www.meccano.us/differential_analyzers/robinson_da/index.html [accessed 21 October 2017].

machine, nicknamed ‘ART’ after Porter.[650] She explained that Porter – using his [contributory] knowledge of the original differential analyser – had insisted on not using torque amplifiers due to the challenges of building and maintaining them. Bonita explained that the servomechanisms had functioned much more reliably than torque amplifiers would have done; though she made this comment to me based on Porter’s comments, rather than first-hand evidence of using both variations.[651] However, I felt that – as my goal was to recover the contributory expertise and gestural knowledge of the original torque amplifiers and reproduce them in the Kent machine – I could not simply follow Porter’s suggested changes.

Figure 7.4a: An image of Tim Robinson (R) and his Meccano differential analyser. (Image reproduced from http://www.meccano.us/differential_analyzers/robinson_da/vcf70.html).

[650] A servomechanism is an automatic device that ensures the output integral arm of the analyser has the precise amount of torque necessary, compared to the manual torque amplifiers.
[651] Tim Robinson, personal communication, 9 September 2016; and Bonita Lawrence, personal communication, 10 April 2018.

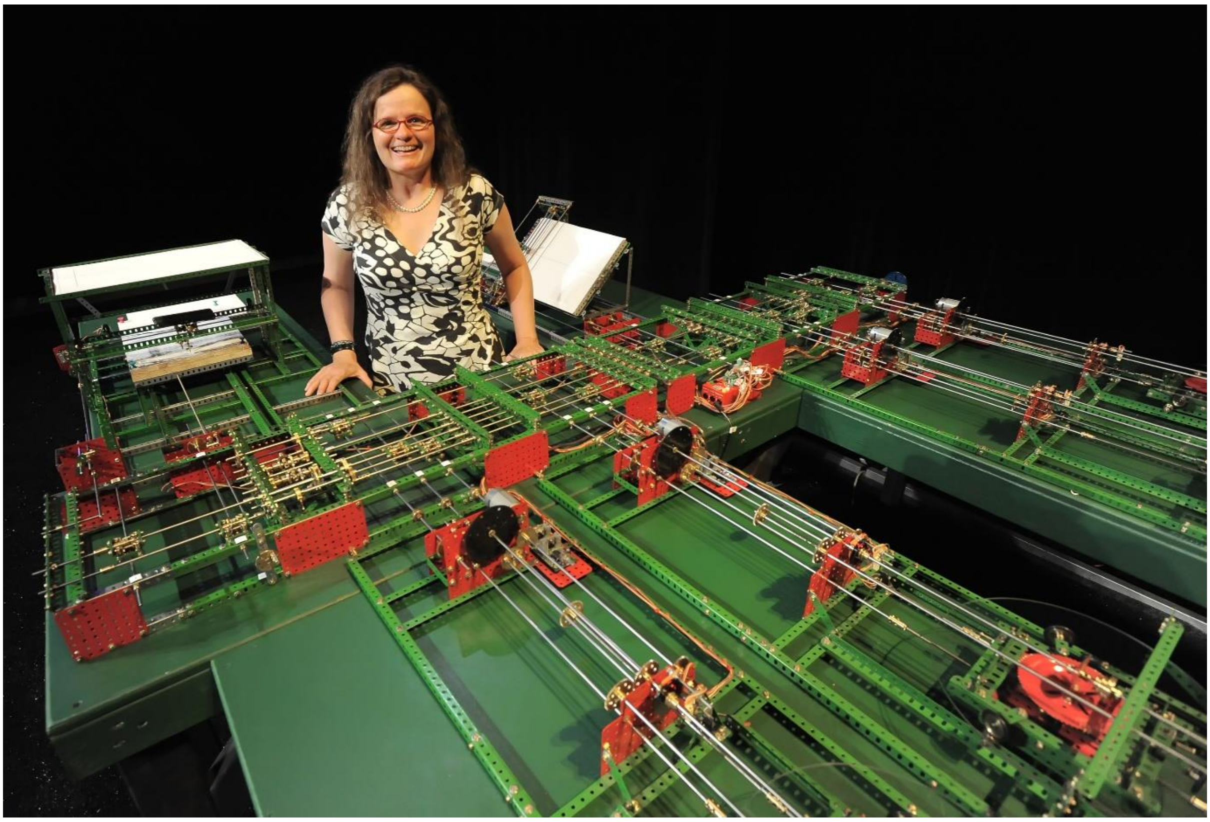

Figure 7.4b: An image of Professor Bonita Lawrence's DA 'Art' at Marshall University. (Image reproduced from https://www.herald-dispatch.com/news/marshall_university/marshall-unveils-differential-analyzer-model-aimed-at-understanding-solving-mathematical/article_c062c56f-7f02-5ba1-8090-839b688f70da.html).

Therefore, I searched through textual sources to find information on the original torque amplifiers that could help me recover Hartree and Porter's contributory knowledge after my initial conversations with Tim and Bonita. Of course, I quickly realised that as Sibum and others have noted, primary textual sources for an original object never reveal the tacit knowledge that was required to build them in the first place.[652] Therefore, next best thing I could do was to see if the Meccanomen's interactional expertise of Meccano would translate to a surviving example of the original differential analyser, and whether this would help me get closer to Hartree and Porter's contributory expertise. To this end, I invited a group of Meccanomen to the Science Museum to engage with the Trainbox.

[652] H. O. Sibum, 'Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England,' *Studies in History and Philosophy of Science Part A,* Vol. 26 (1), (1995), p. 103; M. Usselman, A. Rocke, C. Reinhart, and K. Foulser, 'Restaging Liebig: A Study in the Replication of Experiments,' *Annals of Science*, Vol. 62, (2005), pp. 1-55; and P. Heering, 'The Replication of the Torsion Balance Experiment,' *American Journal of Physics*, Vol. 60 (11), (1992), pp. 988-994.

As discussed in Chapter Four, Hartree constructed the Trainbox in 1947 using parts of the original Meccano differential analyser and 'toured' the object until 1949, before it was collected by Calvert at the Science Museum.[653] Six Meccanomen signed up to visit the museum and analyse the Trainbox. Their interactional knowledge of Meccano gave them the ability to look at the Trainbox and know precisely what Meccano pieces had been used to build it. This was incredibly useful in creating the list of the components needed to reproduce the analyser. However, Brian Elvidge and Robin Schoolar explained that overall, the Trainbox was not a suitable object on which to base a historical reproduction of Kent machine. They identified that the torque amplifiers were not original, that the glass disc had been replaced, that the weights on the output integrator arm had been removed, and that some Meccano had been swapped out for newer, 'anachronistic' parts (see figure 7.5).

Figure 7.5: The Meccanomen attendees at the Science Museum on 8 March 2018. (Left to right), Kim Fisher, Robin Schoolar, Ian Henwood, Matt Goodman, Brian Elvidge, and George Sayell. (Image taken by author).

[653] Science Museum Archives, Sc. M. 1949-134/3, 'Douglas Hartree letter to Henry Calvert, 1 July 1949;' and Science Museum Archives, Sc. M. 1949-134/5, 'Science Museum Object Acquisition Form completed by Richard Hartree, 2003.'

While their perspectives and interactional expertises were useful, they did not bring me closer to recovering the gestural knowledge of Meccano and mathematics that was needed to reproduce the original machine. Fortuitously, for the success of the project, one of the Meccanomen present – Ian Henwood – mentioned that he had built a Meccano differential analyser as part of a 'Young Scientists of the Year' competition on BBC1 in the 1970s. Ian's previous experiences meant that he possessed some aspects of the contributory expertise and gestural knowledge that Hartree and Porter would have used to build their original differential analyser from Meccano.

Ian's contributory expertise and gestural knowledge of differential analysers, along with my primary source knowledge of the original differential analyser were both necessary to inform the design and operation of the Kent machine and its torque amplifiers. The first step we took to reproduce the original torque amplifiers was with a prototype unit based on some of the published drawings and designs of the original differential analyser. We found that these torque amplifiers jammed between 40-50% of the time, causing the machine to stop, contrasting with Hartree's description in 1935 that the amplifiers 'resolved the effect of slippage on the integration of equations.'[654] Nevertheless, after tinkering with the amplifiers for a month, I accepted that we would not be able to recover the tacit knowledge that Hartree and Porter had used to make them work.

While the process of reproducing the original torque amplifiers demonstrated the difficulty of recovering contributory expertise, they also highlighted the importance of gestural knowledge and Ian's ability to improvise solutions. To overcome the unreliability of the torque amplifiers, Ian suggested that we replace them with the fully-Meccano torque

[654] D. R. Hartree, 'The Differential Analyser,' *Nature*, Vol. 136, (1935), pp. 940-943.

amplifier design that he had successfully used to construct his 1970 machine. His design was a variation on the Meccano amplifiers that had appeared in a 1967 *Meccanoman's Club* article on differential analysers.[655] The Meccano nature of these amplifiers deviated from the bespoke, flattened boiler-ends that Hartree and Porter had used in 1934.[656] We had initially ignored these *Meccanomen's Club* designs as we had committed to maintaining complete historical fidelity to the original pieces and design of the 1934 version.[657] However, this first experience of constructing torque amplifiers demonstrated that complete historical fidelity was not going be possible if we wanted to reproduce the original differential analyser successfully. Instead, Ian used his gestural knowledge of Meccano models and computers to improvise a solution to the torque amplifiers that 'infilled' the gaps in his contributory expertise. His solution highlighted that despite his contributory expertise and gestural knowledge of Meccano differential analysers, some aspects of the original were impossible to recover.[658] The alternative torque amplifiers were successfully tested in July 2018, providing better reliability than those used by Hartree and Porter in 1934.

The historiographical significance of reproducing the torque amplifiers on the Kent machine led to a re-evaluation of Hartree's description in 1935 that the amplifiers 'resolved the effect of slippage on the integration of equations.'[659] Before the Kent machine, I had interpreted his words in textual sources literally, believing that the torque amplifiers had represented a solution to the problem of slippage in these types of mechanical machines.[660]

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[655] These Meccano-only amplifiers were developed for the 1967 *Meccanoman's Club* article as the original amplifiers were not made from Meccano.
[656] D. Hartree and A. Porter, 'The Construction and Operation of a Model Differential Analyser,' *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, Vol. 79, (1934), pp. 51–84.
[657] Anon., 'Differential Analyser,' 'The GMM Series of Modern Supermodels,' *Meccanoman's Club*, No. 4, 1967.
[658] These issues of fidelity are discussed further in the following section.
[659] D. R. Hartree, 'The Differential Analyser,' *Nature*, Vol. 136, (1935), pp. 940-943.
[660] These problems of slippage and lack of torque are explained at length in Chapter Two, which discussed the previous failed attempts by Charles Babbage and Lord Kelvin to build their own analogue calculating machines.

However, reproducing the torque amplifiers demonstrated that Hartree's claim about torque amplifiers – while technically correct – is missing a series of qualifiers in relation to how the calibration and programming of the machine for specific equations impacts both accuracy and reliability. This recovered tacit knowledge confirms the challenges of mechanical accuracy and context with these machines in Chapter Two, and also helps us to understand the extensive challenges that the Science Museum experienced with constructing the torque amplifiers for the 'Babbage Difference Engine No. 2' in the early 1990s.[661]

The ease with which Ian repurposed some spare parts to improvise a simple and effective solution to the problem of the torque amplifiers left me scratching my head on two issues. The first issue was whether any Meccanomen other than Ian would have the contributory expertise and gestural knowledge to have improvised this solution. Through working with Ian to construct and use the Kent machine, it was clear that his ability to improvise these solutions was based on the intersection between his gestural knowledge of Meccano and his previous experiences as both an amateur scientist and engineer. His ability to improvise these solutions was unique for Ian, as it is also based on his later career in NHS mental health services, where he has used Meccano as a form of therapy. The intersection of these skills supports the idea that individuals engage with the collective tacit knowledge of society and build their tacit knowledge based on their personal experiences.[662] However, it also demands that we look closer at improvisation as something distinct from the tacit and gestural knowledge described by Sibum and Collins and Evans. While it is impossible to say

[661] For more on the challenges of torque in the Science Museum's project refer to: D. Swade, 'The Construction of Charles Babbage's Difference Engine No. 2,' *IEEE Annals of the History of Computing*, Vol. 27 (3), (August, 2005), pp. 70-88.
[662] H. O. Sibum, 'Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England,' *Studies in History and Philosophy of Science Part A,* Vol. 26 (1), (1995), p. 103; and H. Collins, and R. Evans, *Rethinking Expertise* (University of Chicago Press, 2007), p. 14.

that Ian was the only Meccanoman that could reproduce a differential analyser, it is possible to say he was the only one who could have done it in this improvised, yet precise way.

The second issue relates to the level of skill that Hartree and Porter must have had to successfully construct their machine and make the original torque amplifiers work. Our experiences reproducing the original differential analyser demonstrated that Hartree and Porter must have had a much higher level of interactional and contributory expertise with Meccano and mechanics than is described in textual sources. Their gestural knowledge is not explicitly described or alluded to in any of the published articles relating to the original machine, except in one article in the *Meccano Magazine*, which asserted that Hartree's choice to use Meccano was 'natural,' given the many hours with the toy that he had enjoyed as a boy.[663] However, in subsequent histories written for these machines (and others), there is almost nothing written about the hands-on [gestural] Meccano skills that Hartree and Porter must have possessed to build the original differential analyser. Instead, there are only limited references to Hartree's status as a former 'Meccano boy,' and the idea that Porter may have owned some sets as a child.[664] This example demonstrates that experiencing and solving the challenges relating to reproducing the Kent machine was crucial in helping to uncover gestural knowledge that is missing from textual sources.

Alongside this gestural knowledge, the Kent machine also helped us to recover tacit knowledge of how the original differential analyser functioned. Ian and I had spoken about the gear ratios of the Kent machine on a few occasions throughout the design phase of the project, without coming to a satisfactory conclusion about the importance and function of the 6:1 gear ratio that existed on the original object. As the significance of the 6:1 gear ratio

[663] E. Hawks, 'Meccano Aids Scientific Research,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 441.
[664] C. Froese Fischer, *Douglas Rayner Hartree: His Life in Science and Computing* (World Scientific Publishing, 2003); and Arthur Porter, interviewed by Tim Robinson, 8 March 2008, Computer History Museum, X4583.2008.

was not explicated in articles on the original differential analyser, we believed that it was arbitrary and decided to use a 4.5:1 gear ratio on the Kent machine as it was a more readily available piece. After making this decision to use a different gear ratio, we forgot that we had made this change, and continued to reproduce other parts of the machine. However, the tacit knowledge of the significance of the gear ratio later became apparent when we used the machine to resolve a simple velocity-time equation at the University of Kent in October 2018.

Ian and I were joined at the University of Kent by Meccanoman Matt Goodman, just before one of these 'Eureka' moments occurred on the second day of testing the completed Kent machine. Matt compared the values of the output curve with the number given by the revolution counter, which measured the rotations of the output integral arm of the machine. For this particular equation, the revolution counter displayed the number twenty-one (21), indicating that in the rate of change equation we had used, the distance the car had travelled was 21 metres. In contrast to this number, the output table produced a curved line on a piece of graph paper that showed the car had only travelled between 4.6 and 4.7 metres. We could not explain this difference in the output values of the machine, before Ian shouted:

> Eureka! I've got it! Matt, Tom, what is 4.65 x 4.5?[665]

The answer to this question is 20.925, or 21, as was displayed on the revolution counter. Ian had realised that the 4.5:1 gear ratio of the Kent machine and the 6:1 ratio of the original machine programmed their scaling factors. Matt then explained that if there were no scaling factors, the tables on the Kent machine would have needed to be 4.5 times larger,

[665] Ian Henwood, personal communication, 8 October 2018.

which would have ‘increased the challenge of [the input operator] manually following the line on the input table with the necessary level of accuracy.’[666]

The historiographical importance of recovering this contributory expertise and gestural knowledge of the original differential analyser with the Kent machine cannot be understated. It had only been by reproducing the processes involved with using a differential analyser to resolve an equation that the relationship between the components of the object, and their impact on the analyser’s function, became apparent. Recovering this contributory knowledge of the scaling factors changed our understanding of why the original differential analyser had been built in the way it was, while also helping us to realise that the specific gearing ratio of an analyser was important in determining the overall size and accuracy rate of the original machine. From initially believing that the gear ratios were arbitrary (as they did not feature in textual sources), it had been our inadvertent decision to ignore this aspect of historical fidelity that allowed us to recover this tacit knowledge of the original differential analyser. When I spoke to Bonita and Tim about this realisation, they explained that they had used the 6:1 gear ratio without realising its significance to the overall design and application of their machines. Therefore, this recovered tacit knowledge has historiographical significance as it provides a different perspective of how differential analysers were built and functioned on a practical basis, the level of Hartree and Porter’s skill, and how unreliable the machine was in reality, especially compared to how it was described in textual sources.

[666] Matt Goodman, personal communication, 9 October 2018.

3. Historical Fidelity

Historical fidelity is a term used by historians of science to measure the similarity of a reproduced experiment or machine to the original. Hjalmar Fors, Lawrence Principe, and Otto Sibum's work on this issue concluded that a '…high level of fidelity to the original process, apparatus, or experimental protocol is not always necessary to carry out a historically informative reproduction,' and that a historian can choose to ignore some aspects of fidelity to simplify the process of reproducing an object.[667] While it is important to maintain a high level of historical fidelity in historical reproductions, the previous section demonstrated that ignoring it can inadvertently help us to recover contributory expertise and gestural knowledge that would be impossible to recover had we maintained complete fidelity. Peter Heering's 'The Replication of the Torsion Balance Experiment' (1992), which approached Coulomb's torsion balance experiment, is an example of a historical reproduction that benefited as a result of the challenges associated with historical fidelity. Heering demonstrates the challenge of maintaining the fidelity of design and components when reproducing machines and experiments. He described his struggles replicating Coulomb's electrostatic force law due to his inability to replicate the same 'pith spheres,' whose age determined their electrical stability and impacted the overall experimental method. However, Heering considers that his inability to maintain complete historical fidelity to the components of the original did not detract from tacit knowledge that he recovered. Therefore, similar to how the tacit knowledge that we recovered reproducing the torque amplifiers changed how I understood textual sources on the original analyser, Heering used his inability to maintain complete

[667] H. Fors, L. M. Principe, and H. O. Sibum, 'From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science,' *Ambix*, Vol. 63 (2), (2016), p. 94.

historical fidelity to suggest that Coulomb may not have reported his methods and original data honestly.[668]

The Kent machine was designed as a historical reproduction of the original differential analyser, which meant that we aimed to include as many 'flaws' from the original as possible. When it became clear that complete historical fidelity would be impossible, we agreed that our aim should be to reproduce the Kent machine as close to the original as possible. This section analyses the aspects of fidelity that we chose to be faithful to and those we ignored, and the impact that these choices had on the tacit knowledge that was recovered. It focuses on three separate areas of historical fidelity with the Kent machine, including its design, components, and materials. It considers the challenges of maintaining historical fidelity in these three areas, the changes we were forced to make, how they impacted the reproduced machine compared to the original, and subsequently, the tacit knowledge that was recovered.

The first challenge of historical fidelity that we faced in attempting to reproduce the Kent machine from the original differential analyser was, which version? For the ease of analysis, Chapter Two discussed the original differential analyser as a single iteration. However, Arthur Porter originally constructed a single-integrator prototype in 1933, which was then rebuilt and expanded into a two-integrator, and later a three-integrator differential analyser, all of which featured in the June 1934 issue of the *Meccano Magazine*. We decided to reproduce the Kent machine based on the designs of the three-integrator version that featured in the June 1934 issue of the *Meccano Magazine*.[669] The reason for this was that it was the most complete iteration of the original machine. As well as featuring in the article 'Machine Solves Mathematical Problems: A Wonderful Meccano Mechanism,' it also featured

[668] P. Heering, 'The Replication of the Torsion Balance Experiment,' *American Journal of Physics*, Vol. 60 (11), (1992), pp. 988-994.
[669] *Meccano Magazine*, Vol. XIX, No. 6, pp. 441-444

in a series of other articles and books written by Hartree and Porter, John Crank, and Vannevar Bush (see figure 2.22b).[670] After deciding to base the Kent machine on these *Meccano Magazine* designs, the issue of aesthetics vs. reality quickly became apparent. We noticed the 'Meccano-fication' approach used by the Hawks featured in the image of Porter's proof-of-concept model (see figure 2.24). As discussed there, the 'Meccano-fication' of the original differential analyser – designed to make it a more comprehensible object for readers – resulted in a mathematically impossible image. However, as these were the only published images of the original differential analyser, we faced the following question of historical fidelity: 'What should we be faithful to, an impossible picture, or a no longer existing material object?'

We spent time considering this issue and decided to sacrifice historical fidelity on this occasion and ignore the incongruous design aspects in these images. We believed that by ignoring them, we would be able to recover some other tacit knowledge through reproducing the original differential analyser as a machine that could be used to integrate equations, rather than one that would not function. To infill this gap and maintain the highest level of historical fidelity possible, we relied on the other schematic descriptions of the differential analyser, Ian's tacit and gestural knowledge of previously building this type of machine, and his improvisational skills.

The 'Eureka!' moment discussed in the previous section demonstrated that our decision not to maintain the highest level of fidelity to the original design inadvertently allowed us to recover tacit knowledge about how the machine had worked. This was despite

[670] E. Hawks and D. R. Hartree, 'Machine Solves Mathematical Problems: A Wonderful Meccano Mechanism,' *Meccano Magazine*, Vol. XIX, No. 6, p. 442; D. R. Hartree, *Calculating Instruments and Machines* (University of Illinois Press, 1949); V. Bush, 'Instrumental analysis,' *Bulletin of the American Mathematical Society*, Vol. 42 (10), (1936), pp. 649-669, and J. Crank, *Differential Analysers* (Longmans, 1947).

scaling factors being a very visible physical part of the Trainbox portion of the original differential analyser that sits in the Science Museum (see figure 7.6).

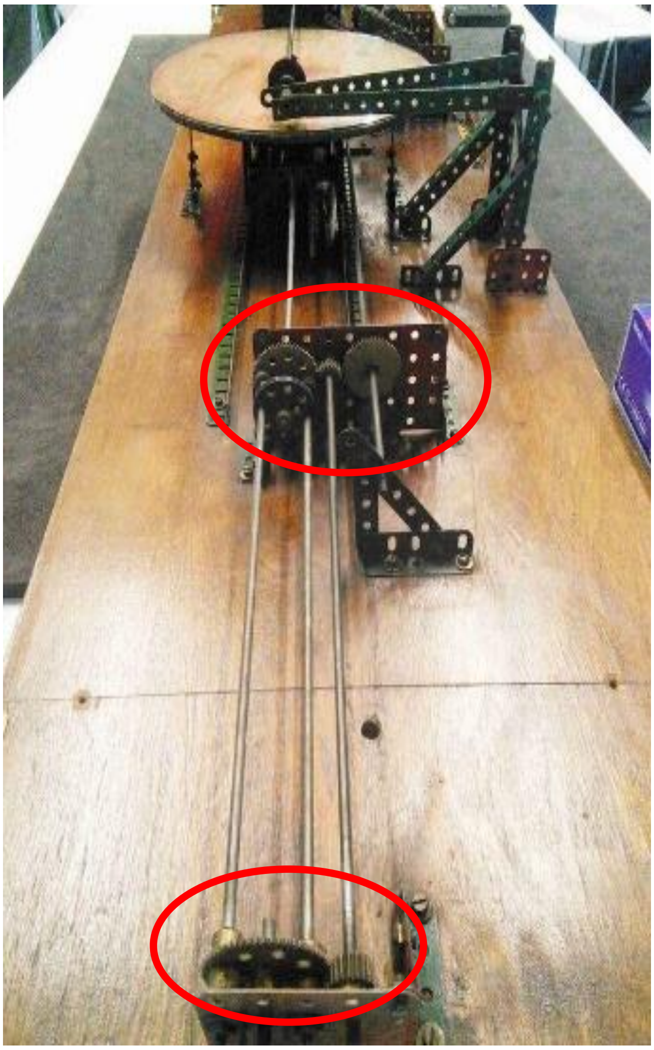

Figure 7.6: An image of the Trainbox demonstrating the scaling factors of the object (circled). (Image taken by author).

Put simply, they were not something the Meccanomen or Ian had been aware of when we viewed the Trainbox at the Science Museum (despite Ian having rebuilt a differential analyser with scaling factors previously). We only learned about the practical impact of different gear ratios on the function and design of the rest of the machine by using a 4.5:1 gear ratio instead of the 6:1 ratio from the original design. However, an unintended outcome of these different scaling factors was the impact they had on our ability to be faithful to the instrumentality of the original differential analyser, as they meant that we used a smaller input and output table.

These smaller tables increased the margin of error we had with the Kent machine when we manually following the input line, which reduced the level of historical fidelity when compared to the original. Despite this, we found that by using a smaller input table, our 'error' in fidelity had helped us recover tacit knowledge that allowed us to understand the original machine better.

The list of Meccano pieces that the group of six Meccanomen helped to create during our first trip to the Science Museum led to an overarching question of historical fidelity about what Meccano pieces we should use in our reproduction. I initially tried to source the pieces we needed from the few remaining distributors in the UK, but found that our demand outstripped supply.[671] As happened many times throughout this project, Ian presented a solution, explaining that many Meccanomen had begun to create their own Meccano pieces after Meccano Ltd. went into administration in the UK in 1981. He told me that he was one of these Meccanomen, and had taken it upon himself two decades previously to create pre-war pieces of Meccano – to the original specifications – in his garage, using various lathes, jig borers, and gear shapers.[672] Ian's production of homemade Meccano pieces represents what Mark Duffett describes as a 'moment of agency'; the idea that as a fan of Meccano, he is motivated to build these pieces to help others experience it in the way that he did growing up.[673] Therefore, reproducing the Kent machine represented a further moment of agency for

[671] The reasons why my attempts to use this type of Meccano failed are discussed in Chapter Five. That chapter described how pre-war pieces of Meccano became increasingly rare after the 1964 takeover by Lines Bros., who focused on the production of Plastic Meccano sets.

[672] Meccano enthusiasts led by collector Geoff Wright bought surplus sets of redundant parts from Meccano France in the late 1980s to bolster the economy of usable Meccano parts from the pre-war outfits. He is credited for 'saving the adult hobby from extinction' by the International Society of Meccanomen, http://internationalmeccanomen.org.uk/ISM/GSAward/album/2007%20Geoff%20Wright%20%20(United%20Kingdom)/slides/03%20Geoff%20in%20Meccano%20Wonderland.html [accessed 10 October 2018].

[673] M. Duffett, *Understanding Fandom: An Introduction to the Study of Media Fan Culture* (Bloomsbury, 2013), p. 23.

Ian, as it also allowed him to reshape the public history of Meccano and the original differential analyser.

The completed Kent machine included many original pre-war Meccano parts, as well as those that Ian had made, including universal couplings, drive-shafts, helical gears, and torque amplifiers.[674] The low availability of original pre-war pieces meant that whether I took the decision to try and source them (delaying the project in the process), or decided to use Ian's homemade pieces, there would be an issue of fidelity with the materials and components we used to construct the Kent machine. Before deciding on which Meccano to use, I also spoke with Meccanomen and dealers. One told me that very often, the '…original Meccano gears would not mesh correctly, and the struts had holes that were often misaligned.'[675] Another told me that Ian's homemade Meccano was renowned among the membership, 'for the high standard of craftsmanship and level of accuracy when compared to the production value of pre-war Meccano.'[676] Therefore, based on these endorsements, I decided to use both original pieces and Ian's homemade pieces, despite their increased level of accuracy. This decision came after constructing the prototype units of the Kent machine, and recovering the tacit knowledge of the temperamental nature of the components. Based on these experiences, we agreed that we needed to reduce and remove as many maintenance problems and challenges as possible, in order to demonstrate the Kent machine successfully.

However, the decision to construct the Kent machine from more accurate pieces of Meccano (than Hartree and Porter would have been able to consistently access) created a

[674] Ian's ability to make 'personal' Meccano pieces originally featured in the previous section on tacit knowledge. However, I felt it made more sense to include in fidelity, as it was a decision we took to use his pieces, rather than something the success of the machine relied on, as we could have found original pieces elsewhere eventually.
[675] James Starling, personal communication, 9 July 2018.
[676] Kevin Fischer, personal communication, 6 July 2018.

further question of whether the higher reliability created a fidelity challenge of instrumentality. Put simply, had we, by virtue of using more accurate pieces, unintentionally made the instrumentality of the Kent machine too accurate compared to the original? The answer to this question was alluded to in Chapter Two, which demonstrated that the mechanical accuracy rate of the original machine correlated to the accuracy of the pieces and the way that they were configured for each equation. It also explained that the overall accuracy rate of differential analyser depended on the skill of the operator, which made it virtually impossible for Hartree and Porter to duplicate the published 98% accuracy rate of their machine for different equations, let alone us with our reproduced Kent machine. Therefore, we ultimately ignored this potential issue of fidelity, accepting that even if we could maintain 100% fidelity to the materials and components of the original machine, we would not be able to achieve the same accuracy rates as the original for each equation.

In summary, the Kent machine stands apart from other historical reproductions as we had to manage the conflict of designing it to be both a historically accurate reproduction of the original differential analyser and as a public engagement object. This meant that we had to tread a very fine line, making sure that we were faithful to the errors that featured in Hartree and Porter's design, while also making sure the Kent machine was reliable. Balancing these competing needs helped us to both recover aspects of Hartree and Porter's tacit and gestural knowledge, and improvise solutions for these errors to ensure the machine could work. Therefore, the challenges of fidelity that we faced in our attempts to create the Kent machine were a blessing as they provided a glimpse into the work that Hartree and Porter had completed to construct the original. However, it was also a curse for the same reason, as my desire to maintain the highest fidelity to the original differential analyser, but also make it reliable enough to function as a public demonstration model, effectively doubled our workload.

The process of constructing the Kent machine tended to move between exciting and frustrating as we were aware of solutions – such as the servo mechanism – that would have made building and using the Kent machine much easier and cheaper. Despite this, I found that the challenges of trying to maintain fidelity and improvise solutions did more than help recover elements of Hartree and Porter's tacit and gestural knowledge. By intentionally reproducing the same errors that Hartree and Porter made with the original differential analyser and then resolving them with the Kent machine, our explicit and tacit knowledge of how a differential analyser functions were also increased. Based on these experiences, future historical reproductions would benefit from going beyond simply maintaining historical fidelity and instead engage with the conflicts caused by reproducing errors and then work to resolve them historically.[677]

[677] H. Fors, L. M. Principe, and H. O. Sibum, 'From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science,' *Ambix*, Vol. 63 (2), (2016), p. 94.

4. Public Engagement

Public engagement with historical research and objects allows traditional histories to be challenged outside of the academic setting. It does this by inviting non-professional historians to be a part of the process of creating public history. This type of 'history from below' was developed under Samuel in the 1970s 'History Workshop' movement. He believed that through collaborating with non-professional historians to create knowledge about the past, our understanding of the past could be liberated from the confines of the libraries and archival sources.[678] On the value of engaging the public with the Kent machine, Hilda Kean and Paul Martin assert that when laypeople engage with the past, they participate in a 'democratic interpretation' of what they can see, which changes the meanings and understandings that they and historians have previously placed on objects.[679] The decision to demonstrate the Kent machine publicly and create its public history with these audiences built on the successful collaboration with the Meccanomen in the previous chapter to co-curate their historiographical perspectives by virtue of the same 'shared authority.' The aim of engaging in this 'shared authority' was to demonstrate that the public histories of these analogue computers are far richer than is suggested in the current exhibition of the Trainbox in the Science Museum.

I hoped that by demonstrating the Kent machine, I would encourage nostalgic memories from those who have played with Meccano, while also introducing them to complex STEM concepts along the way. However, to properly engage with and reshape the public history of the Kent machine, I needed to balance my role as a communicator of stories,

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[678] H. Kean, P. Martin, and S. J. Morgan (eds.), *Seeing History: Public History in Britain Now* (Francis Boutle Publishers, 2000), p. 14; and J. de Groot, *Consuming History: Historians and Heritage in Contemporary Popular Culture* (Routledge, 2009), pp. 104: 117.

[679] H. Kean and P. Martin (eds.), *The Public History Reader* (Routledge, 2013), p. 8.

with being a mediator that defends against non-historical analysis. My approach to demonstrating the machine carried risks of a promoting non-historical analysis, as I promoted the first presentation of the Kent machine as a 'playful demonstration,' which included letting the audience play with and build their own Meccano models. The purpose of this was to encourage the audience to engage with Meccano in a tactile way before we demonstrated the differential analysis in a hands-on way, using the Kent machine. The poster created to advertise the event reflected these stories, including an image of an original Meccano toy advert, an image of the original differential analyser, and the following blurb (see figure 7.7).

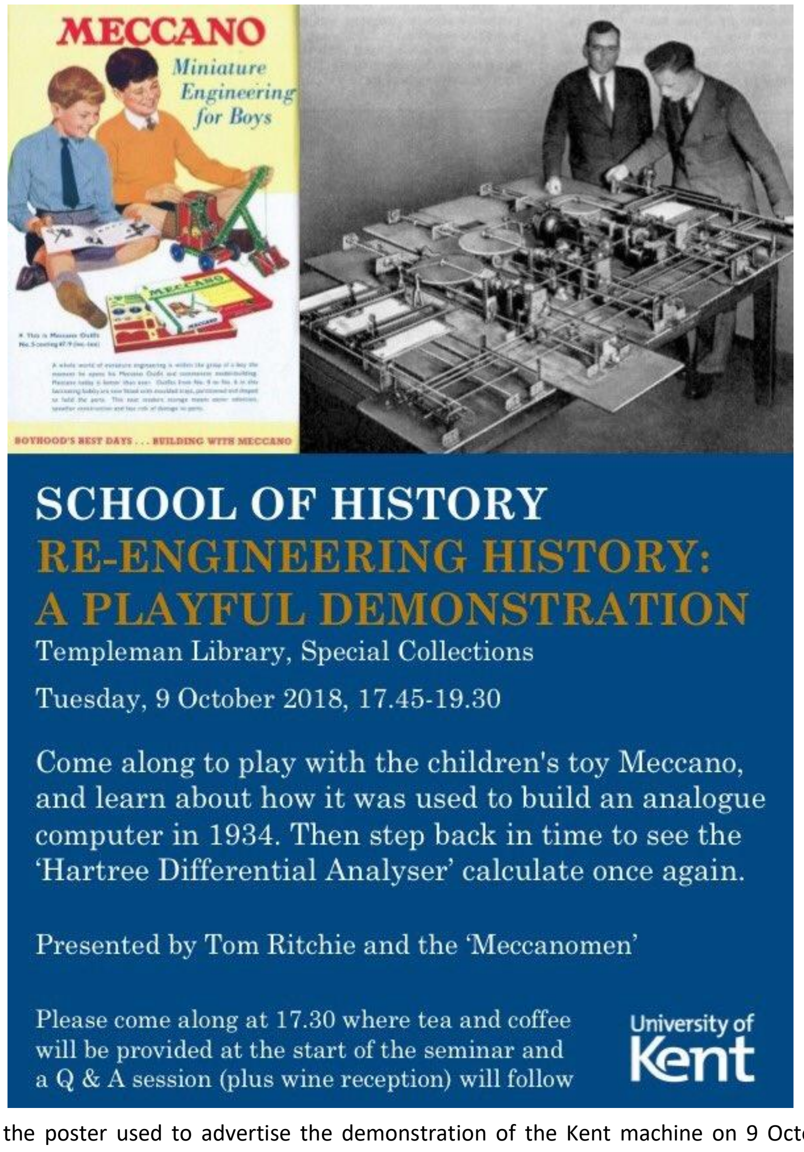

Figure 7.7: Part of the poster used to advertise the demonstration of the Kent machine on 9 October 2018 at the University of Kent. (Image created by author).

I am happy to admit that there was a historiographical alarm sounding as I wrote this poster and my presentation materials, as of course, we were not stepping back in time to see the 'Hartree Differential Analyser' as that title is both misleading, and was not the name given to the original Meccano differential analyser. Instead, audiences were viewing a reproduction that did not have complete fidelity of design, material, or function, which made it different from the original differential analyser. However, I decided to promote the demonstration in this way to ensure that the event was popular, following Jordanova's notion that the role of the historian in presenting public history is as an 'architect of public attitudes of the past.'[680] Therefore, while, I acted – to an extent – in bad faith by playing on the nostalgia for Meccano that people may have had from their childhoods, the ends justified the means. A useful comparator project is the recent Constructing Scientific Communities project, which similarly tolerates this type of presentism – addressing nineteenth-century natural knowledge networks as 'citizen science' – in the interests of promoting broader engagement.[681]

The first 'playful demonstration' attracted a broad range of over 50 attendees, ranging from a four-year-old girl (she asked her parents to come) to various professors of computing, mathematics, and engineering, with whom I could co-curate the public history of the Kent machine. While public engagement offers varied opportunities to those presenting the material to reshape and re-contextualise the understanding of a machine or concept, the role also carries risks of authority. These risks are best encapsulated in Jordanova's question, 'who may speak with authority about the past, and by virtue of what qualities?'[682] I felt confident that as a professional historical researcher of Meccano, Hartree and Porter, and their original

680 L. Jordanova, 'Public History,' *History Today*, Vol. 50 (5) (May, 2000).
681 For further information on the Constructing Scientific Communities project and 'citizen science,' refer to www.conscicom.web.ox.ac.uk [accessed 20 July 2019].
682 L. Jordanova, 'Public History,' *History Today*, Vol. 50 (5) (May, 2000).

differential analyser, I could speak with authority about the Kent machine. However, mine was not the only voice that had the authority to speak; through being collaborators on the project, Ian Henwood and Matt Goodman also had this 'shared authority.'[683] The rest of this section analyses the challenges of public engagement that I experienced when cultivating a public history for the Kent machine. It considers the conflicting approaches of Matt and myself during the first presentation of the machine, before discussing how different audiences have used their 'shared authority' to change the public history of the Kent machine.

Before discussing the conflicts of 'shared authority,' it is necessary to understand the different 'bases of authority' that informed Ian's, Matt's, and my perspectives on the Kent machine.[684] I sought to shape the public history of the Kent machine to demonstrate that it is a complex system of analogue computing, which was once a well-established viable alternative to digital methods, deviating from the public history of the Trainbox.[685] While Ian's view of the public history of the Kent machine had been shaped during our close collaboration throughout the project, Matt – as a relative latecomer – approached it from a different perspective. Instead of a historical reproduction of a complex mathematical machine, Matt wanted to present the Kent machine as a simple 'Meccano mechanism,' akin to any other crane or train that he may build to demonstrate at his quarterly Meccanomen meetings. The difference between conflicting types of authority in these presentation styles is captured in Iwan Morus's contrast of Michael Faraday's presentations of science at the Royal Society with William Sturgeon's performances at the Adelaide Gallery.

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683 M. Frisch, *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (University of New York Press, 1990), p. xxiii.

684 Ibid., p. xxii.

685 J. Small, *The Analogue Alternative, The Electronic Analogue Computer in Britain and the USA, 1930-1975* (Routledge, 2013).

Morus explores how their opposite approaches to constructing spaces helped to shape the public performance of their experiments and the knowledge that they developed among their audiences. He explained that while Faraday's presentations were performed in exclusive surroundings and aimed at the elite in society, Sturgeon's were aimed at those in society who enjoyed theatrical shows and entertainment. [686] The different approaches Matt and I used were crucial to understanding the conflicts of 'shared authority' that occurred during this first presentation. On reflection, I sought to emulate Sturgeon's 'judicious arrangement of phenomena,' by emphasising the history, context, and complexity of the Kent machine as if it were the original differential analyser; a complex mathematical object that had been created from a simple children's toy. I tried to tell as many stories of the original differential analyser as possible, so that the audience could understand the rich history of analogue machines in Britain. The stories that I told during the demonstration included the history of Meccano, who Hartree and Porter were, and the applications of analogue computers before, during, and after the Second World War. I also encouraged the audience to reflect on the conventional public histories of the original differential analyser, which has existed as a 'Mechanical Marvel,' an analogue computer, a wartime device, a toy, and a collected museum object. The purpose of highlighting these different public histories was to ensure that the audience could understand the Meccano and mathematical aspects of the machine and engage with them, while also reaffirming the historicity of the Kent machine as a reproduction of the original differential analyser.

In contrast, Matt presented the Kent machine in a way that was much closer to Faraday's more exclusive approach. In the final hours before our demonstration that Matt

[686] I. R. Morus, *Frankenstein's Children: Electricity, Exhibition, and Experiment in Early Nineteenth-Century London* (Princeton University Press, 1998), p. 101.

commented that he did not agree with the way that I intended to present the Kent machine. He believed that our primary aim should be to simplify the machine and the equations it could be used to perform as much as possible. Instead of using the machine to explore the complex histories of Meccano and differential analyser, he asserted that we should emphasise the simplicity of the machine, to the extent that we should even avoid using certain words. These included the words, 'complex,' 'clever,' 'differential,' and 'calculus,' which he felt would make the Kent machine appear to be too complicated, 'when in reality it was just a simple Meccano model.'[687] I argued that from a historical perspective, it would be challenging not to use the words 'differential' and 'calculus' when discussing a 'differential analyser,' and that if we did not explain them, there was a risk the audience would not be able to follow the overall story that I wanted to convey. I also reiterated that the reason why I wanted to demonstrate the Kent machine in the first place was a desire to reshape the public history of the original differential analyser and Trainbox.

Matt believed that we should use 'simple facts' to explain the Kent machine as a relatively simple mathematical object that had been created from the ingenious tool of Meccano, in contrast to my approach of explaining a complex mathematical concept using Meccano.[688] I believe that Matt's desire to paint Meccano as an ingenious tool related to his belief that it is more than a toy. While I agreed with Matt's perspective on Meccano being more than a toy, my concern with his desire to keep the maths of the machine simple was that he assumed too much mathematical knowledge on the part of the audience. His approach risked making the public history of the Kent machine into something opaque and difficult to follow, excluding most in attendance. I explained that I had purposely promoted

[687] Matt Goodman, personal communication, 9 October 2018.
[688] Matt Goodman, personal communication, 9 October 2018.

Meccano in a 'playful' way in advertising materials, to communicate to potential audience members that the demonstration would not be overly academic and that through the child's toy, the complexities of the machine would be made accessible for any level of education.

I reflected on whether previous interactions with Matt may reveal why he wanted to present the machine in this way since this first demonstration of the Kent machine. When I interviewed Matt in 2016 (in his capacity as a Meccanomen), I asked, 'Do you think if more young people used Meccano today, it would benefit the national good of Britain? If yes, please explain why?' In response, Matt explained, 'Of course…it requires a mind that can see the real world and use its parts to replicate part of it… [Meccano] is a gift to an enquiring mind [and should] be used for original design and development.'[689] During the presentation of the Kent machine, Matt replicated this view, telling the audience that Meccano 'was well enough conceived by Hornby to surpass its simplicity.'[690] The challenge with his approach of not explicitly telling the audience how exactly Hornby had 'well enough conceived' Meccano for this purpose, was that it relied on the presumption that the audience possessed the same tacit knowledge that he did for both Meccano and differential analysis. For Matt, who had made Meccano models and machines for over fifty years, the machine was an extension of his hobby, something he – as a Chairman of the West London Meccano Society club – wanted to promote it as an iterative and straightforward object. However, for many members of the audience, Meccano, and the concept of differential analysis, were things they most likely would have had little previous experience of in their day-to-day lives. Morus discusses this aspect of Faraday's presentations, describing how his approach meant that 'Experiment and

[689] Matt Goodman, personal interview, 10 April 2016.
[690] Matt Goodman, personal interview, 10 April 2016.

discovery [became] provinces of the trained elite whose expert knowledge gave them privileged access to natural phenomena.'[691]

Despite the conflicts between Matt's and my presentations, making good public history requires a 'shared authority' between historians and non-historians.[692] Therefore, I ensured that both Matt's and Ian's voice were reflected in this demonstration of the Kent machine. We agreed that I would present the history and context of the machine, Matt would explain the analyser in his simpler terms, and then Ian would take the lead on demonstrating the Kent machine (see figure 7.8).

Figure 7.8: An image from the demonstration of the Kent machine that took place on 9 October at the University of Kent. (Image taken by author).

Although I worked hard to mediate between our perspectives during the presentation, the conflict of authority between Matt and I quickly became apparent. It occurred when I commented that the original differential analyser and the Kent machine were 'incredibly smart bits of kit, which, with enough work, could be useful today.' Matt interjected to correct

[691] I. R. Morus, *Frankenstein's Children: Electricity, Exhibition, and Experiment in Early Nineteenth Century London* (Princeton University Press, 1998), p. 5.
[692] T. Cauvin, *Public History: A Textbook of Practice* (Routledge, 2016), p. 12: 205-217.

me, saying that it was not smart, but was ‘supremely simple’ and could be understood very easily.[693] I did not try to correct Matt, but instead carried on introducing the original differential analyser as a complex mathematical machine. I told the audience that despite its complexity, we were going to learn about it together during the presentation by first playing with and discussing Meccano. As I listened to Matt’s description of the machine, I felt that his simple approach was perhaps part of a feigned humility; by presenting the mathematics of the machine in a simple way to emphasise the complexity of Meccano, Matt, like Faraday, tried to make himself as the master over both.

Nevertheless, the differences between Matt’s perspective and my own highlight the vital role that historians of science play as mediators when presenting reproductions and historical artefacts. The conflicts in our presentation style demonstrate that the public history of the Kent machine was at stake, and the way that we engaged the public with the machine required great care, as it would shape their understanding of particular topic or theme.[694] These conflicts also highlight the challenge of cultivating public history through public engagement, especially as Matt’s approach was not encumbered by the same responsibilities of cultivating good public history that I had to consider.

The comments and questions made by the audience during the initial demonstration have also become a part of the public history of the Kent machine. For example, during the demonstration of the Kent machine, Daniel Bearup (a Lecturer in Mathematics at the University of Kent) commented that upon seeing the machine working, he realised that the analogue method of the machine would benefit his current research. He explained that despite being a technology created over eight decades ago, the Kent machine ‘provided the

[693] Matt Goodman, ‘Playful Demonstration’ Workshop, 9 October 2018.
[694] L. Jordanova, ‘Public History,’ *History Today*, Vol. 50 (5), (May, 2000).

opportunity to see if an equation was working during the process of calculation, rather than at the end, as with digital computers.'[695] His comments confirmed to me that publicly demonstrating the Kent machine had gone some way in satisfying my original desire to reshape the public history of the Trainbox in the Science Museum. I included Daniel's comments in subsequent demonstrations of the Kent machine, to realise the audiences' 'shared authority' over the public history of the Kent machine. His comments support the public history I was trying to cultivate; that despite being a historical reproduction, the Kent machine demonstrates that there is contemporary research value for this 'outdated' analogue technology.

During the subsequent tour of the Kent machine, I noticed that the public history of the Kent machine that I cultivated became increasingly similar to how Douglas Hartree demonstrated the Trainbox at different universities from 1947-49.[696] Without realising it, I had essentially ventriloquised aspects of his tour of the Trainbox in an attempt to embody an idealised version of Hartree in my own tour. An example of this is where Hartree had used the tour of the Trainbox to demonstrate 'all the main principles' of his differential analysers, I used the tour of the Kent machine to demonstrate 'all the main principles' associated with historically reproducing the original differential analyser from Meccano.[697] The result of this ventriloquism was that Hartree was the hero of the story within the public history of the Kent machine that I presented, often at the expense of Porter. Richard Westfall discusses a similar experience in an article that followed his biography of Isaac Newton in 1980, *Never at Rest*.[698] He explains that he had downplayed aspects of Newton's life to preserve his reputation as an

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[695] Daniel Bearup, personal communication, 9 October 2018.
[696] B. Latour, *Pandora's Hope: Essays on the Reality of Science Studies* (Harvard University Press, 1999), p. 304.
[697] Science Museum Archives, Sc. M. 1949-134/3, 'Hartree letter to Calvert, 14 July 1949.'
[698] R. S. Westfall, 'Newton and his Biographer,' in S. H. Baron, and C. Pletsch (eds.), *Introspection in Biography: The Biographer's Quest for Self-Awareness* (The Analytic Press, 1985), pp. 175–189.

‘unworldly scholar,’ framing Newton as ‘a portrait of my ideal self, of the self I would like to be.’[699] Patricia Fara, echoing Westfall, asserts that in her career she also created her own version of the past, ‘select[ing] a female hero whose characteristics matched those evoked for [her].’[700] Similar to both Westfall and Fara, I am aware that I initially used Hartree as an analogue for myself in the story that I use the machine to tell; an awkward, bespectacled, and bookish man who travelled around teaching people about how a Meccano machine (that had a profound effect on his life and career) worked (see figure 7.9).

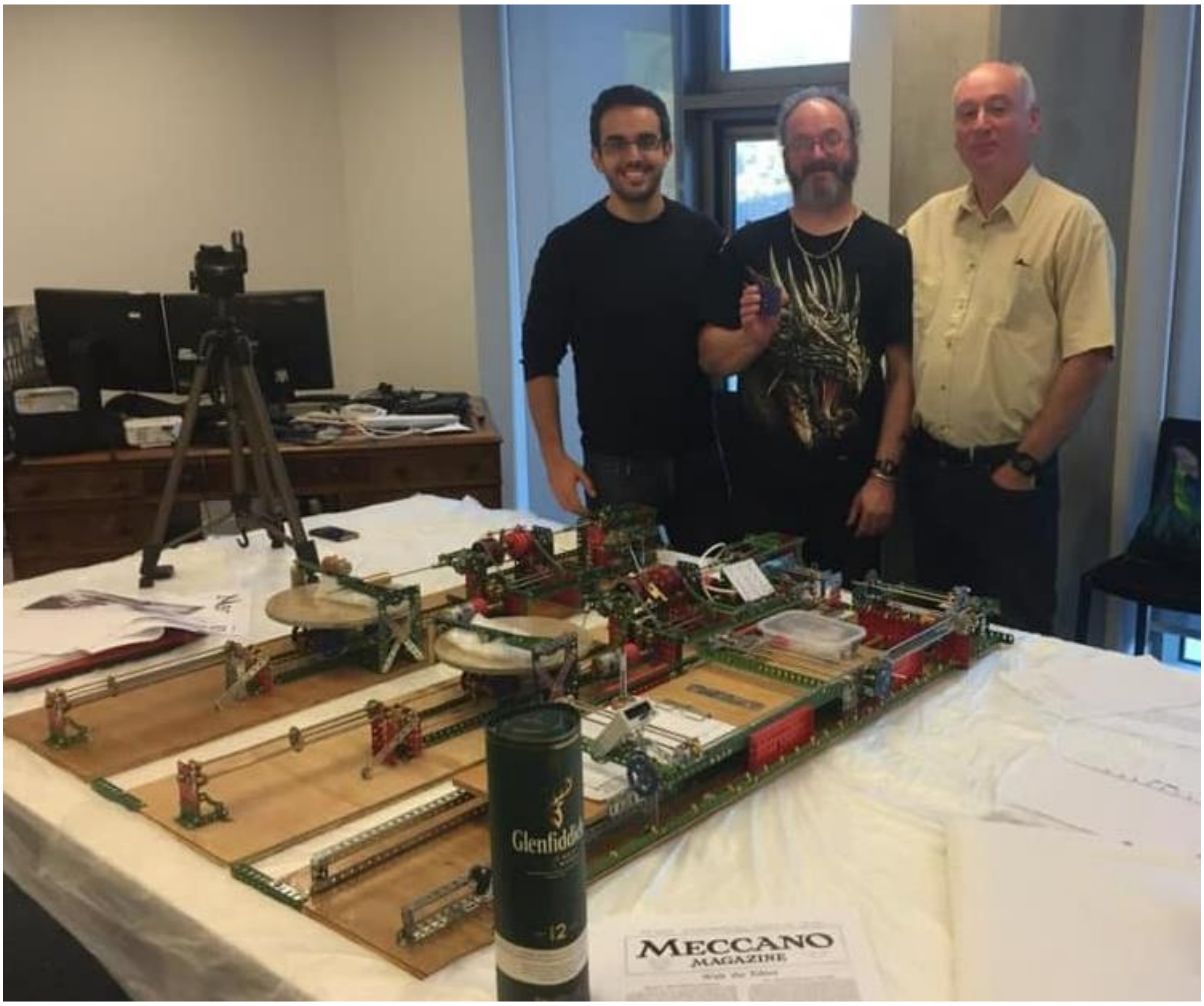


Figure 7.9: An image taken at the culmination of the reproducing the Kent machine on 11 October, 2018. (Left to right), Tom Ritchie, Ian Henwood, and Matt Goodman, with the Kent machine in the mid-ground, and next to a copy of the original *Meccano Magazine* article from 1934. (Image taken by Karen Brayshaw).

[699] Ibid., p. 188.
[700] P. Fara, ‘The Past is a Work in Progress,’ *British Journal for the History of Science*, Vol. 51 (1), (March 2018), p. 10.

Reflecting on the early demonstrations of the machine, I am aware that I tended to cultivate a public history of the original differential analyser that focused on Hartree. However, as a result of a presentation that I was invited to give at Marshall University by Bonita, this Hartree-centred public history of the Kent machine was fundamentally changed for the better. The public history of the Kent machine that I presented in West Virginia was different from those than I had previously told, as this was the first presentation that did not feature a demonstration of the Kent machine (as it was too big and fragile to be transported by aeroplane – though it was suggested I should turn my machine into a 'Planebox,' to mimic Hartree's Trainbox). Instead of using the historically reproduced Kent machine to explain Meccano and differential analysis to the audience, I used Bonita's mathematically reproduced analyser 'ART,' named after Arthur Porter. The audience for the presentation was also different from any I had previously encountered, comprising almost exclusively of mathematics staff and graduate students. To cater to this audience, I changed the public history that I presented; instead of Meccano, I discussed Erector (the Americanised variant), I reduced the introductory content on the mathematics of the original differential analyser, and focused on the contrasts between the historically reproduced Kent machine and 'ART.'

Where I would had previously focused on Hartree in the public history of the Kent machine, Bonita, and by extension the audience, (many of whom had previously used the appropriately named 'ART') instead focused on Arthur Porter. This inevitably led to a conflict of authority, when Bonita commented that I was wrong in my description that there was no evidence that differential analysers had been used to resolve calculations related to the bouncing bombs (Operation Chastise).[701] She called out during the presentation that 'Arthur

[701] For more on 'Operation Chastise,' refer to D. C. Dildy, *Dambusters: Operation Chastise* (Osprey Publishing, 2010).

Porter told me that it did.’ This required me to clarify that Porter had finished working with the British differential analysers in 1937, and that there were no primary sources that support this application of the Manchester machine.[702] Despite this, she reiterated that he had told her that it had been used for this application when they met, adding a new dimension to the public history of the machine I was describing. The absence of the Kent machine in this presentation meant that I incorporated the tacit knowledge of Porter’s, which Bonita had relied on to build ‘ART’ in 2007, alongside the tacit knowledge I had recovered with the Kent machine.

There were other occasions during the presentation that Bonita sought to add Arthur Porter into the public history that I was telling, raising his role to one equivalent to Hartree. I encouraged this and incorporated her experiences and discussions with Porter into the public history of the differential analysis that I told, which led to a much greater emphasis on the contrast between the mathematically constructed ‘ART’ in comparison to the historically reproduced Kent machine. I had been worried that this improvised change to the public history of the machine to make it include the shared stories of Porter and Hartree may have been confusing for those in attendance. However, I was told afterwards that by presenting the two reconstructed machines in contrast to each other and debating Bonita, members of the audience felt ‘as if Porter and Hartree had been here to explain it all themselves.’[703]

The interactions with Bonita and the audience at Marshall University changed the public history that I have used the Kent machine to tell in subsequent demonstrations (see figure 7.10). I have moved away from using Hartree as an analogue for myself, and instead

[702] Bonita Lawrence, personal communication, 29 April 2019. Chapter Three discussed Operation Chastise and the likelihood that differential analysers were used, analysing the testimony of Maurice Wilkes, who, like Porter did not work on the British differential analysers during this period.
[703] HollyAnn Swann, personal communication, 30 April 2019.

consciously tried to cultivate a public history of the original differential analyser that includes both Hartree and Porter as primary protagonists.

Figure 7.10: The top image is from the lecture I delivered based on the Henwood-Lawrence machine at Marshall University, while the bottom image is with Professor Bonita Lawrence and her differential analyser, 'ART.' (Images reproduced with permission of Clayton Brooks).

5. Conclusion

At the time of writing, reproducing and presenting the Kent machine has been transformational for my research, and as such is something that historians may wish to incorporate into future research projects that incorporate objects. The experience has highlighted the challenges of reproducing historical objects with complete fidelity and has helped to reframe much of how textual sources describe Hartree, Porter, Meccano, differential analysis, and how the original differential analyser worked. It has also changed my understanding of both tacit and gestural knowledge, as they are demarcated in Collins and Evans' categories of interactional and contributory expertise and Sibum's gestural research in his on James Joule.[704] While these concepts help to explain much of what we recovered with the Kent machine, they provide a limited characterisation of Ian's ability to improvise solutions to problems we faced. However, I believe that Ian's ability to improvise solutions for the Kent machine was the result of more than his interactional expertise of Meccano. From working closely with Ian, his ability to improvise is not a single type of tacit knowledge, but instead sits at a nexus point between his interactional expertise of Meccano, his contributory expertise of the differential analyser, and his gestural knowledge of building complex Meccano models of larger real-world machines.

The public demonstrations of the Kent machine have also introduced me to the critical role that I play as a historian of science in shaping the public history of an object for different audiences. To fulfil my responsibility as a public historian that encourages 'shared authority,' I used the presentation in West Virginia as a platform to celebrate the crucial roles that Ian

[704] H. Collins, and R. Evans, *Rethinking Expertise* (University of Chicago Press, 2007); and H. O. Sibum, 'Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England,' *Studies in History and Philosophy of Science Part A,* Vol. 26 (1), (1995), pp. 73-106.

and Bonita played in the realisation of this project. At the end of the presentation I announced that I was renaming the Kent machine as the ‘Henwood-Lawrence’ machine. I chose to rename the Kent machine in this way, after I learned of the Science Museum’s decision to collect it at the end of my Ph.D. The fact that the Henwood-Lawrence machine is a historical reproduction means that it does not need to be preserved in the same way as the Trainbox, which means it can fulfil this role of being used as an object that is actively demonstrated for museum visitors.

While I never intended the Henwood-Lawrence machine to feature in the Science Museum, I insisted on this name in the hope that it informs the way it is used to actively engage the public with analogue computing. I also hoped that the by renaming it as Henwood-Lawrence machine, it will also encourage people to engage with the public history of Meccano and the Meccanomen, and the efforts of Bonita and Tim in reconstructing their machines. I am also hopeful that this new name will reflect the co-curated public history of the reproduced machine, as one that tells the stories of the Meccanomen and audiences (through the inclusion of Henwood) and Hartree, Porter, and mathematics (through Lawrence). The intention is that it will teach museum visitors about the technology of the past through a physical demonstration of its function, rather than reading a ventriloquised description on an exhibition label. The irony of my insistence on this new name for the Kent machine, which effectively ventriloquised its voice and changed its meanings is not lost on me. The impact of changing the name of the Kent machine to tell a different story demonstrates how far object developers – including Hartree and myself – are able to control and influence the naming and interpretation of their objects.

The effect that this project has had outside of my Ph.D. also extends to a series of other Meccano differential analysers built by the Meccanomen. These machines include those made by Ian Henwood, Matt Goodman, and George Sayell, who has written two articles on his ‘Heath-Robinson Differential Analyser’ for the *Midlands Meccano Guild Bulletin* (see figure 7.11).[705]

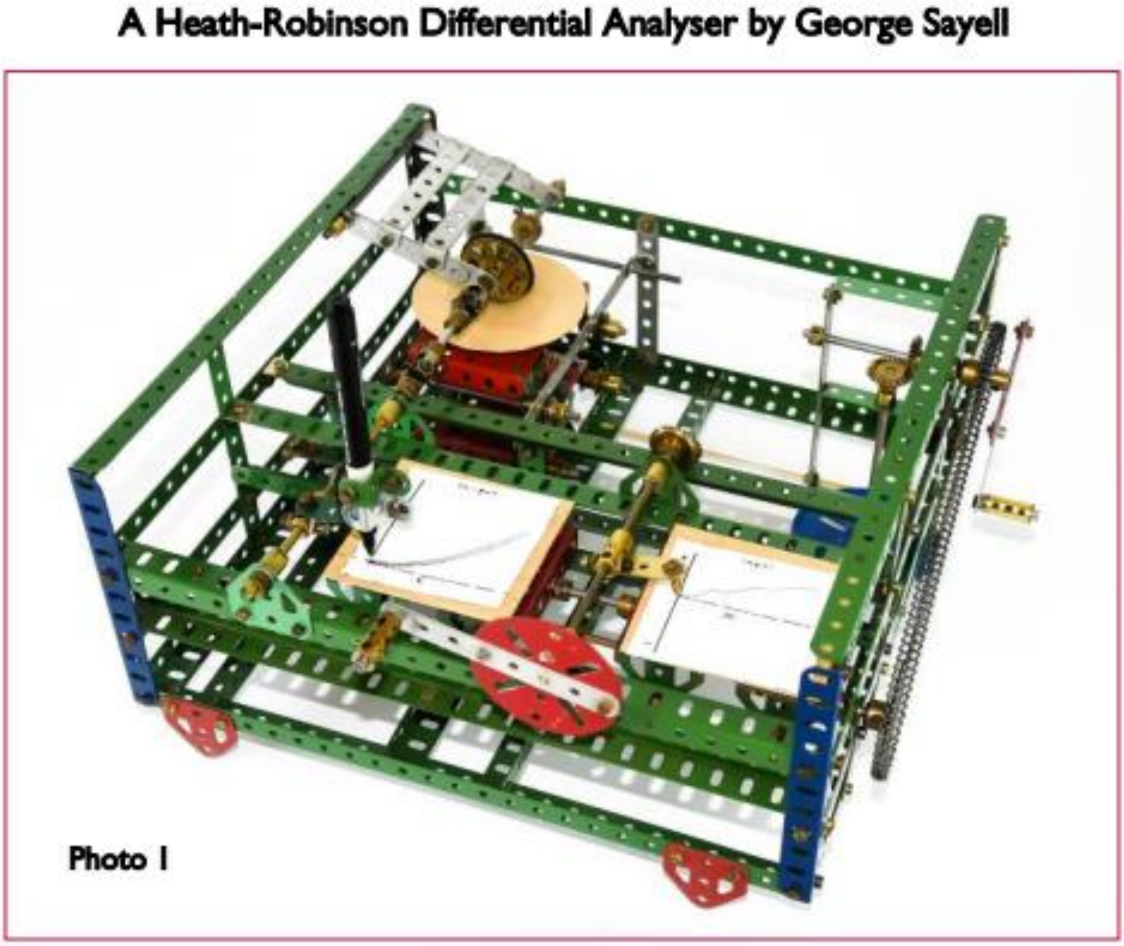


Figure 7.11: An image of the Heath-Robinson Differential Analyser constructed by George Sayell, who visited the Science Museum in March 2018. (Image reproduced from *Midlands Meccano Guild Bulletin*, Issue 75, (December 2018)).

The unique tacit and gestural knowledge, and improvisational skills that the Meccanomen have used to create these variations of the original differential analyser is apparent in the design and function of each of their machines. The subsequent creation and display of these machines at Meccanomen meetings have also had the effect of reinvigorating

[705] G. Sayell, *Midlands Meccano Guild Bulletin*, Issue 73, (April, 2018), pp. 12-14; and G. Sayell, *Midlands Meccano Guild Bulletin*, Issue 75, (December, 2018), pp. 4-9.

the history of Meccano and the differential analyser among the Meccanomen. This has resulted in many of them contacting me to tell about their experiences of building Meccano differential analysers, and requesting the opportunity to present their machines. To support their desire, I worked with the British Science Association to secure a space for them at the British Science Festival in September 2019. At this event, the Meccanomen were able to educate the public on their Meccano hobby through their personal reproductions of the original differential analyser and other Meccano objects.

This success of the public demonstrations and the Science Museum's decision to collect the machine, confirm that the Henwood-Lawrence machine has provided the 'life-enhancing experiences' that Tim Boon asserted that Collaborative Doctoral Partnerships (like this project) should provide the public.[706] On reflection, I am confident that historically reproducing the Kent machine and co-curating its public history as the Henwood-Lawrence machine with the Meccanomen, audiences, and Bonita has had both a transformational effect on me as a historian, my research, and this thesis.

[706] T. Boon, 'Co-Curation and the Public History of Science and Technology,' *Curator: The Museum Journal*, Vol. 54 (4), (October, 2011), pp. 383-387; and National Museum of Science and Industry, 'Defining, Planning, and Measuring a Life-enhancing Experience,' *Internal Guidance Document*, (2009).

Conclusion: An Assemblage of Assemblages

Whether something is described as having an object biography, or as part of an ontology of things, material culture literature increasingly treats the object and subject as two elements that need to be 'folded into each other.'[707] While Daniel Miller asserts that objects contain meaning beyond their form, function, and instrumentality, historians have neglected to analyse objects in a way that folds these separate elements of meaning into different groups of subjects.[708] Perhaps the closest to this approach is Christopher Tilley's call for a phenomenology of objects, in which he states that these properties of the object are not independent, but part of a whole that is interpreted by the subject.[709] However, his approach still defines the object in relation to the perspective of a subject at a given moment in time.

In order to deconstruct the original Meccano differential analyser, this thesis has incorporated elements from these different material culture approaches. The primary approach treats it as an assemblage of different physical and metaphorical parts that have interacted with audiences and changed over time. Martin Müller describes assemblages as 'a mode of ordering heterogeneous entities so that they work together for a certain time.'[710] This thesis analysed the object in this way as it sought to consider the two central aspects of the internal object assemblage; its materiality as a Meccano model and instrumentality as an analogue computer. With this approach, it has established that the two aspects of this internal assemblage have changed over time as a result of being part of external assemblages with Meccano and the Meccanomen, the 'analogue gap' in the history of computing scholarship,

[707] C. Pinney, 'Automonsters' in P. Wollen, and J. Kerr (eds.), *Autopia: Cars and Culture* (Reaktion Books, 2002), p. 228.
[708] D. Miller (ed.), *Material Cultures: Why Some Things Matter* (UCL Press, 1998), p. 12.
[709] C. Tilley, *The Materiality of Stone: Explorations in Landscape Phenomenology* (Berg, 2004), p. 12.
[710] M. Müller, 'Assemblages and Actor-networks: Rethinking Socio-material Power, Politics and Space,' *Geography Compass*, Vol. 9 (1), (2015), pp. 33-35.

and how the original object has been accessioned and used by the Science Museum. The interactions of these different internal and external assemblages over time are what made the original Meccano differential analyser and the Trainbox object interesting examples to explore and deconstruct in a way that challenged their conventional public histories. The thesis then sought to co-curate a public history for the historically reproduced, reconstructed Kent machine that reflected the complex relationships between these assemblages.

The collaborative approach taken to reconstructing the Kent machine and curating a public history via 'shared authority' also provided the opportunity to get 'hands-on' with the Meccano and analogue computing aspects of the object that Hartree and Porter created in 1934. This process turned the Kent machine into the Henwood-Lawrence machine, a Meccano analogue computer with a public history that directly contrasts to the ventriloquised Trainbox object in the Science Museum. The sections conclusion will reflect further on these themes and the methods used to explore them, reiterating how approaching the original Meccano differential analyser as an assemblage of assemblages has helped to develop our understanding of how 'we make things, things make us.'[711] It will also discuss areas of these themes that require further analysis, as well as areas for future research.

[711] D. Miller (ed.), *Materiality* (Duke University Press, 2005), p. 256.

1. Meccano, Science, and Oral History

The semiotic analysis of Meccano and the *Meccano Magazine* in Chapter One demonstrated that the conventional public history of Meccano (that situates the toy as a synecdoche for British engineering) is based on a 'particular solidarity' of the object's history as a synchronic toy, which has resulted in an 'imagined community' of homogenous users, for whom it is believed the toy provided a single 'technical vision' before the Second World War.[712] However, through analysing the archival sources on Meccano and voices of users in the *Meccano Magazine*, the chapter established that Frank Hornby used a variety of signifiers to transform his invention from a child's educational toy, into a commodity for would-be engineers, before Ellison Hawks developed it into an aspirational emblem of fan-participation in international science and engineering before the Second World War. This analysis also introduced the idea of 'Meccano-fication,' which would go on to play a significant role in subsequent analyses of Meccano. Overall, it established that the Meccano boys (who would later become the Meccanomen) were a heterogeneous group of users, who used the toy in a variety of different ways, which highlighted that Meccano was not a homogenous engineering toy when Hartree and Porter used it to build the original differential analyser in 1934.

Chapter Five explored the second part of the Meccano story, analysing the development of the 'mainstream' and 'alternative' versions of the toy that developed after the Second World War. It established that previous Meccano scholarship had told two separate stories, with academics using it as an economic example of Britain's post-war

[712] Kroto's interview in which he discussed the 'demise of British engineering' was on a BBC Radio 4 episode of *Desert Island Discs,* https://www.bbc.co.uk/programmes/p00948nr [accessed 4 July 2016]; R. Wainman, '"Engineering for Boys": Meccano and the Shaping of a Technical Vision of Boyhood in Twentieth-Century Britain,' *The Journal of the Social History Society*, Vol. 14 (3), (2017), pp. 381-396; and P. Bowler, '*Meccano Magazine:* Boys' Toys and the Popularisation of Science in Early Twentieth-Century Britain,' *British Journal for the History of Science: Themes*, Vol. 3, (2018), pp. 129-146.

decline, and amateurs using it to construct nostalgia-driven public histories.[713] Instead, the chapter combined these two approaches to tell the story of Meccano as a cultural and economic object since the Second World War. It demonstrated how the changes made to the 'mainstream' version of Meccano after the Second World War were a crucial factor in the formation of the 'alternative' Meccanomen movement in 1965, as enthusiasts shifted from passive consumers to active producers of their Meccano hobby and publications.[714] It also highlighted that in their desire to return to their nostalgic 'golden age' of Meccano and British engineering from before the Second World War, the early Meccanomen took up the mantle of Hornby to develop an 'alternative' version that they believed he 'would have wanted.'

The chapter also demonstrated that the establishment of alternative equivalents (the *Meccanoman's Journal* and the regional groups) alongside their 'mainstream' counterparts (the *Meccano Magazine*, and the Meccano Guild) meant that the two versions continued to directly impact each other until Meccano Ltd. ceased operating in Britain in 1981. This analysis of post-war Meccano developed on Cavicchi's notion of the 'fannish self' by demonstrating how for the Meccanomen movement, the 'golden age' that had initially defined them was reshaped by its reflexivity and users. It also demonstrated that based on his commitment to innovation, Hornby would not have wanted their version. It then further explored this heterogeneity of the Meccanomen through introducing the testimony of Matt Goodman, the Chairman of the West London Meccano Society. His responses indicated that the Meccanomen had developed their hobby away from the conventional public history of

[713] K. D. Brown, *Factory of Dreams: A History of Meccano Ltd.* (Crucible Books, 2007); K. D. Brown, 'Death of a Dinosaur: Meccano of Liverpool, 1908-1979,' *Business Archives: Sources and History*, Vol. 66, (1993), p. 35 and R. Marriott, *Meccano* (Shire Publications, 2016).

[714] M. Duffett, *Understanding Fandom: An Introduction to the Study of Media Fan Culture* (Bloomsbury, 2013), p. 178.

Meccano in favour of one that reflected their personal experiences, rather than nostalgia for a past they did not live through.

Chapter Six analysed a series of interviews that I had conducted with the Meccanomen, as well as voices from the Oral History British Science Archives at the British Library. In order to answer and extend upon Merchant's call for historians of science to more critically engage with the composure of respondents, I cultivated the interviews to be spaces where we could have robust discussions about their views on 'golden ages' of Meccano, engineering, and popular British decline. However, rather than simply collecting their historical reflections, I combined elements of oral history and public history to create a format where I could work with them to co-curate their 'participant historiographies' of the conventional public history of Meccano. Their responses established that the individual Meccanomen understand, interpret, and use Meccano in a variety of different ways that do not fit with the conventional public history of the hobby, and that lack of 'discomposure' highlighted how they identify themselves in relation to the formal Meccanomen structures.

The analysis of Meccano in these chapters demonstrated that it is an assemblage of its various uses and signifiers, different object biographies, and wider phenomenology of its users, all of which have extensively changed since 1901. This multifaceted approach took previously underutilised archival sources and the voices of users into account, providing a richer understanding of Meccano as an object, an engineering tool, and as part of a hobby.

2. Analogue Computers, the Trainbox, and the Museum

The second part of this thesis focused on the instrumentality of the original Meccano differential analyser as a mechanical analogue computer and attempted to situate Hartree and Porter's machine within the existing history of computing scholarship. It sought to demonstrate that the original differential analyser was a significant co-actor, rather than a linearly-related precursor to digital computers. In doing so, it provides a unique case study that both considers the intersection between the materiality of a toy and the functionality of a computer, while also further contributing to the academic literature that has defined itself in opposition to the Whiggish history of computing.

Chapter Two attempted to close the 'analogue gap' by introducing and analysing the 'nuts and bolts' of the original differential analyser, demonstrating how the different units functioned to resolve equations in reality. It focused on providing a more realistic analysis of the benefits and drawbacks of the analyser, demonstrating that the 98% mechanical accuracy rate was an arbitrary figure that corresponded to the precision of its pieces, but not the relative skill of its operator's ability to configure the machine. It demonstrated that the accuracy rate varied with each equation that was programmed into the machine. The chapter then contrasted the realistic instrumentality of the mechanical method with how the object was presented as a 'demonstration model' in academic publications and as a 'Mechanical Marvel' in the *Meccano Magazine*.[715]

Chapter Three built on this analysis of the original differential analyser's instrumentality by exploring the stories and applications of other British Meccano and non-

[715] D. R. Hartree, and A. Porter, 'The Construction and Operation of a Model Differential Analyser,' *Memoirs and Proceedings of the Manchester Literary and Philosophical Society*, Vol. 79, (1934), pp. 51–84; and E. Hawks, 'Meccano Aids Scientific Research,' *Meccano Magazine*, Vol. XIX, No. 6, (June, 1934), p. 441.

Meccano differential analysers built before, during, and after the Second World War for the first time. The purpose of telling these stories was to provide case studies that closed the 'analogue gap.' It did this by establishing that these machines made significant wartime contributions and establishing that Bush's MIT machine in 1931 was not 'the last gasp for analogue computing.'[716] Through telling the stories of these computers as individual machines with different applications, rather than the homogenous 'analogue computers,' the chapter also provided a new explanation for why Hartree used pieces of Meccano from the original differential analyser to build the Trainbox teaching tool in 1947. The chapter's exploration of British analogue computers demonstrated that the separation of analogue and digital computers as linearly-related technologies needs to be further reconsidered in the history of computing scholarship, and in how these objects are presented in museums.

Chapter Four took a different approach to understand the 'analogue gap,' investigating the ways that the Trainbox has been changed in the Science Museum since it was collected in 1949. The chapter utilised a phenomenological approach to understand how the Trainbox object has been changed on a 'hands-on' level by the processes of accessioning and display, making it tell myriad stories in the Science Museum. It built on previous scholarship on how objects change in museums – that assert that objects have significant 'ages' in their museum careers – by establishing the impact that the voices ventriloquised through the object have had on subsequent reinterpretations.[717] Through introducing the analogy of ventriloquism and the idea that the Trainbox has had different voices (to tell different stories about the physical and instrumental functions of the original differential analyser), the thesis built on Daston's 'loquacious palimpsests,' and Tilley's semiotic approach

[716] W. Isaacson, *The Innovators* (Simon and Schuster, 2014), pp. 36-38: 72-78.
[717] S. J. M. M. Alberti, 'Objects and the Museum,' *Isis*, Vol. 96, (2005), p. 571.

to understanding objects as metaphor.[718] It demonstrated that as much as the other changing cultural aspects of its Meccano materiality and analogue computer instrumentality, being in the museum has also had a significant impact on the Trainbox, in particular, the development of the 'Model Walkway' in the Science Museum, which led a new 'universal language' to be ventriloquised through the object.[719] The analysis of the Trainbox as a ventriloquised object that has a series of different voices helped to establish that being collected by the Science Museum has become part of the assemblage of the original differential analyser, alongside its Meccano materiality and analogue computer instrumentality.

[718] L. Daston, *Things That Talk: Object Lessons from Art and Science* (Zone Books, 2004), p. 223; and C. Tilley, *Metaphor and Material Culture* (Blackwell Publishers, 1999).
[719] Science Museum Informal Collection, D. Woodcock, 'Making the Modern World, Model Walkway Summary Document' (2000).

3. Co-curating the Public History of the Kent machine

This thesis has also sought to understand the original Meccano differential analyser through deconstructing the public histories of the external assemblages that are attached to the object. It then engaged in the concept of 'shared authority' to reconstruct the Kent machine and the public history of its Meccano materiality and instrumentality as a mechanical analogue computer.[720] Chapter Six systematically worked with the Meccanomen to encourage them to co-curate 'participant historiographies' that challenged the conventional public history of Meccano. Chapter Seven then built on this by extending elements of Hilary Geoghegan's belief that interacting with enthusiast communities is important in creating public history.[721] To achieve this, I collaborated with multiple enthusiast communities – in the form of the Meccanomen and Professor Bonita Lawrence and Tim Robinson in the USA – to historically reproduce the original Meccano differential analyser as the Kent machine.

Chapter Seven explores how reproducing the Kent machine as both a Meccano model and a mechanical analogue computer was significant in helping to recover the tacit and gestural knowledge that Hartree and Porter would have used to construct the original differential analyser from Meccano in 1934. The second half of the chapter then described how I brought these groups together with audiences at public demonstrations, to co-curate a public history for the Kent machine that reflected the internal and external assemblages of its Meccano and analogue computer identities from previous chapters. It then explored the challenges associated with this process of reproduction and co-curation, in particular, my collaborators' insistence on their own authority in public demonstrations. This required me

[720] M. Frisch, *A Shared Authority: Essays on the Craft and Meaning of Oral and Public History* (University of New York Press, 1990).
[721] H. Geoghegan, 'A New Pattern for Historical Geography: Working with Enthusiast Communities and Public History,' *Journal of Historical Geography*, Vol. 46, (2014), pp. 105-107.

to accommodate them as best I could, meaning that I was often forced to facilitate, rather than directly lead discussions in some instances, often underplaying my role and research as a professional historian. While this was perhaps the most challenging aspect of this work, these experiences demonstrated to me that the process of co-curation was neither simple nor easy. Nevertheless, these conflicts of authority were an important part of both analysing the assemblage identities of the Kent machine, and engaging in a 'shared authority' that resulted in the co-curation of the public history as the Henwood-Lawrence machine.

The public history of the Henwood-Lawrence machine is an assemblage of its physical pieces, its instrumentality as a historical reproduction of an analogue computer, and the publics with whom I collaborated. The 'shared authority' used to cultivate this public history meant that it directly contrasted to the public history of the ventriloquised Trainbox object in the Science Museum. It was interesting to see how the public history of the object developed in subsequent demonstrations, including at the British Science Festival in September 2019, where the machine was featured at the centre of the festival hub. Instead of being used to represent the story of Hartree, Meccano, and analogue computers, or British Science (as per the festival), Matt Goodman, Ian Henwood and I used it to tell stories that engaged children with hands-on science and engineering concepts, before we gave them Meccano sets of their own. It will also be intriguing to observe how the public history of the machine changes after the Science Museum collects and accessions it May 2020, and whether the voice of the machine is ventriloquised in a similar way to the Trainbox discussed in Chapter Four.

Put simply, the Henwood-Lawrence machine is a physical embodiment of the central priorities of this thesis, which was an attempt to better understand the original Meccano differential analyser by exploring it as an assemblage of internal and external assemblages. This attempt to co-curate a new public history for a historical reproduction that is based on wider historical research provides an example for how historians of science can better understand objects and engage the public with their future research. The co-curation of the public history of the Kent machine, which turned it into the Henwood-Lawrence machine was my attempt to address the complex interaction between these two parts of the original object. In contrast to the existing literature and primary sources and the Trainbox in the Science Museum, the Henwood-Lawrence machine confounds both the conventional public history of Meccano and the 'analogue gap' in the history of computing. It does this by simultaneously being a Meccano model built on the individual nostalgia of Meccanomen, a historically reproduced object that mimics aspects of the original differential analyser and the Trainbox, and an analogue computer that still has usefulness for mathematicians and engineers.

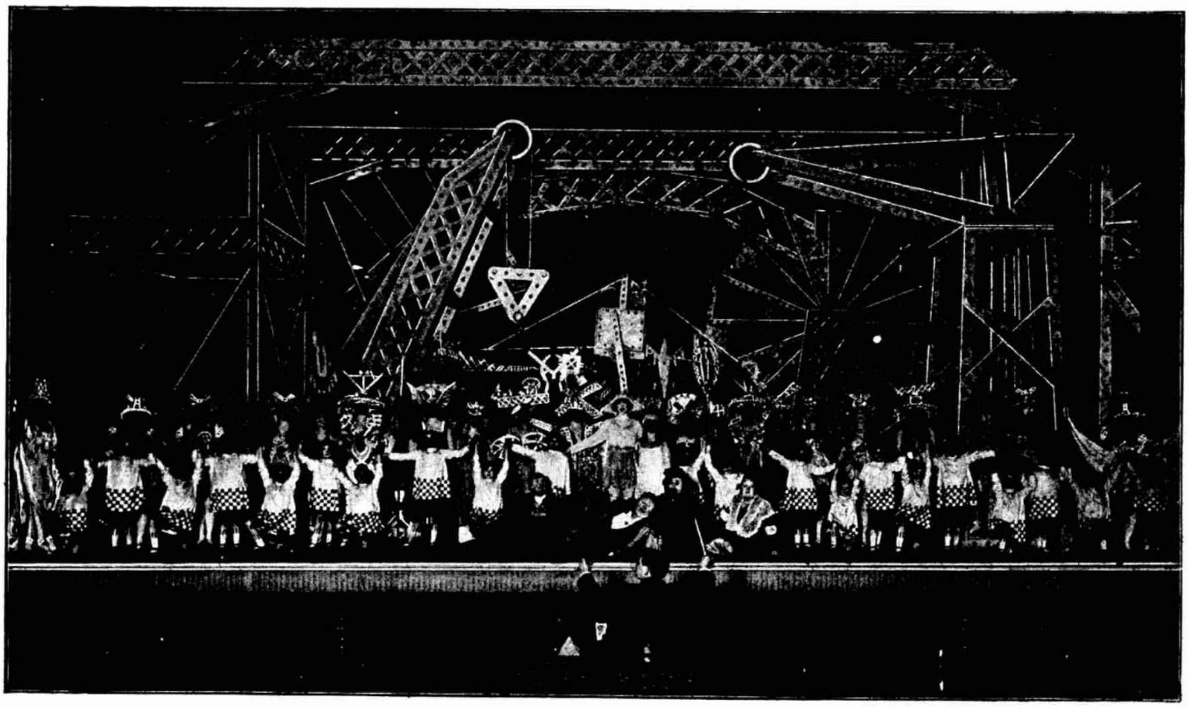
4. Areas for Future Research

There are avenues of research that I did not take in each chapter of this thesis for a variety of reasons. For some, it was an issue of words and space, while for other stories and ideas that were interesting or curious, I found that they ultimately distracted from the story of the original Meccano differential analyser that I was trying to tell. Nevertheless, this section will briefly outline some of these stories and ideas, which could prove to be a rewarding direction for future research into scientific toys, analogue computers, museum objects, and historically reproduced objects.

When using the entire back-catalogue of the *Meccano Magazine* to explore how the toy developed before the Second World War, the story threads available in the 223 issues are too numerous to do them complete justice. One of the most compelling was Hornby's decision to develop a 'Meccanoland' pantomime in the 1910s, which involved a travelling show that used oversized pieces of Meccano to introduce children to engineering through the traditional tale, *Babes in the Wood*. For the pantomime, the magazine 'employed' a correspondent, 'Wee Georgie Wood,' an eight-year-old boy who, performed in the show and wrote articles on it and Meccano from his perspective (see figure 8.1).[722] His is just one example of many fictional characters and themes introduced to the *Meccano Magazine* that were used to shape and change the characteristics of the Meccano boys.

[722] Wee Georgie Wood, 'Meccanoland, A Wonderful Pantomime Scene,' *Meccano Magazine*, Vol. I, No. 6, (February, 1918), p. 2.

2 THE MECCANO MAGAZINE



Meccanoland. A Wonderful Pantomime Scene

A Letter from WEE GEORGIE WOOD to Meccano Boys.

Dear Meccano Boys,

Last time I wrote for the "Meccano Magazine" I said I would tell you all about the wonderful models we have in the pantomime at the Palace Theatre, Manchester—"The Babes in the Wood." I don't think I need do that, because you can see them on the photograph, although they are much more beautiful than any photograph could make them. Therefore, I content myself by explaining the action of the scene.

The Babes are brought out of the woods by good Fairy Joy and taken through Pixie-land to a land of Giant Meccano models. Here we see all the happy little Meccano boys in their familiar check jerseys; we are introduced to the sturdy Captain of the Screwdrivers, who calls upon Father Christmas to show us this wonderful place. The Babes take the journey in a Meccano Motor-car but are followed by the wicked robbers. Robin Hood has them arrested and put away with the spare parts, then arranges for them to get away in a Meccano Aeroplane. The Aeroplane ascends, two massive Cranes start working, a Flip-flap starts working, the Big Wheel goes round, there is a whirling Windmill, and all the inhabitants of Meccanoland turn out; there is singing and dancing and general merriment whilst the Babes fly to safety, and everything ends happily.

All the models are built to scale, and it takes 15 men to keep them working.

The Aeroplane is taken up by means of wires worked by three men, whilst Reggie (that's me) turns a handle to work the propeller. There is a story attached to this: one day I could not get the handle to turn, so the propeller would not work; however, the three men pulled us safely up in the direction of the sky. We had just got to the part when there is a lull in the proceedings, and we heard a small voice from the audience chirp out: "Father, it is not working properly, why don't they have an electric Meccano motor?" I thought it would take a pretty good-sized one. No more now, but I will write some jokes for Meccano boys in the next issue, if the Editor will let me.

Cheerio,

Wee Georgie Wood.

Figure 8.1: An image of the Meccanoland Pantomime. (Image reproduced from *Meccano Magazine*, Vol I, No. 6, 1918).

Beyond this, the *Meccano Magazine* provides an untapped resource of stories about Meccano, boys, science, engineering and play in the twentieth century. It would be interesting to analyse how these characters were used to represent the ideal type of consumer, and how they compare to the portrayal of 'technical youth' in other literature and science-fiction in the first half of the twentieth century. One such example of this science fiction would be the dystopian novel *Meccania: The Super-State* (1918), written by Owen Gregory, which tells the story of Ming Yuen-hwuy, a visitor to the fictional state of Meccania, a place of 'perfect exactness,' propaganda, and 'rigidity' of design.[723]

Another area that I ultimately chose to remove from the thesis was a more detailed discussion about the state of UK and US engineering towards the end of the nineteenth and into the twentieth century, before Vannevar Bush created the MIT machine in 1931. This would have touched on the 'rule of thumb' principle, which prevailed as a result of Samuel Smiles' philosophy that 'fingers are primary inlets of knowledge,' and was perceived as the basis of a sound engineering education, '...[marking] one of the fundamental differences between the incapable man and the man of power.'[724] It would have explored how this perspective helped give rise to John Perry's (Professor of Mechanical Engineering at Finsbury Technical College) 'Perry Movement' in 1882. His movement was based on the belief that 'Man learns to use Calculus as he learns to use the chisel or the file on concrete bits of work, and it is on this idea that I act in teaching the use of Calculus to engineers'.[725] This movement emphasised the necessity of using mechanical machines and graphical outputs within computational engineering in order to increase the practical understanding of mathematics and Calculus. An exploration into this would have contended with how the central themes of the Perry Movement were transformed into what Gardner Anthony (Dean of Engineering at Tufts College, USA) described as 'Graphic Language' in his 1922 book, and correlated this with Bush's perspective that:

> I never consciously taught this man any part of the subject of differential equations; but in building that [MIT] machine, managing it, he learned what differential equations

[723] O. Gregory, *Meccania: The Super-State* (Methuen, 1918).
[724] S. Smiles (ed.), *James Nasmyth: An Autobiography* (London, 1883), p. 97.
[725] J. Perry, Calculus for Engineers (London, 1897), p. 5.

> were himself...It was very interesting to discuss this subject with him because he had learned the calculus in mechanical terms - a strange approach, and yet he understood it. That is, he did not understand it in any formal sense, but he understood the fundamentals; he had it under his skin.[726]

The benefits of the performative nature of the differential analyser, which Bush described as something that 'did more than compute x(t); it kinetically acted out the mathematical equations' briefly featured in my reflections in Chapter Seven about how building and using the machine helped to develop mine and audiences' understanding of calculus. However, an interesting avenue for future research would be a comparison between this machine, believed to be a 'Mechanical Marvel,' and other automata from the past. An example of this would be a comparison with the 'Mechanical Turk,' a machine that was also understood to physically act out equations without human input. The similarities between these two machines, for which the role of humans was initially hidden away in both cases, could help increase our understanding of the relationship between humans and machines. Any future research into Meccano and analogue computers could usefully draw on these links between the performative natures of engineering objects and automata.

Another area of future research for historians of science would be an analysis of how construction toys have changed over the twentieth and twenty-first centuries in terms the science and engineering that they represented, and the impact that they have had in both academic and public contexts. Alongside Meccano, two other examples that I also initially considered for this research were Lego (released in 1949) and Minecraft (released in 2009),

[726] V. Bush, 'Mechanical Solutions of Engineering Problems,' *Tech Engineering News*, Vol. 9, (1928).

which represent aspects of science and engineering culture they were developed in, which were plastic (for Lego) and computing (for Minecraft).

Chapter Three brought together the stories of various British Meccano and non-Meccano differential analysers for the first time, in an attempt to create case studies that help to close the ‘analogue gap.’ However, an area for future research would be to look more widely at other analogue computers developed and used during and after the Second World War. As the size of analogue computers correlates to their complexity, they would have grown to encapsulate entire floors of buildings and research laboratories; the conclusion to Chapter Two alluded to these giant machines, with a brief description of the Rockefeller Differential Analyser in the USA, which had 18 integrating units, weighed over 100 tons, and had 200 miles of wire. While similar-sized analogue machines were built in the UK after the Second World War, they have not been researched or included in the history of computing, something that – due to their size – should be relatively easy to do, as well as something that is long overdue.

Chapter Four explored the development of the Trainbox in the Science Museum, introducing the analogy of ventriloquism to explain the changes made to the object since 1949. A potential area for future research would be to analyse the successor to the original Meccano differential analyser, the Manchester machine, which was split in half and sent to the Science Museum and the Science and Industry Museum (SIM) in Manchester. The diverging uses of the two halves today represent an interesting opportunity to see how museum policies and accessioning procedures can impact the journey of the ‘same’ object in two different museums.[727]

[727] ‘*Mathematics: The Winton* gallery,’ https://www.sciencemuseum.org.uk/see-and-do/mathematics-winton-gallery [accessed 10 February 2018]; and ‘The 1830 Warehouse,’ https://www.scienceandindustrymuseum.org.uk/about-us [accessed 11 February 2018].

Chapter Five explored the two versions of Meccano that developed after the Second World War, highlighting how the Meccanomen became active producers of their hobby, embodying what they believed to be aspects of Frank Hornby. The number of independent publications that the Meccanomen have created since 1965 alongside the *Meccano Magazine*, represent a large area of further research for historians interested in understanding how fan cultures develop. The back catalogue of these sources is relatively straightforward to collect and analyse, but requires a researcher with the time to painstakingly analyse the language and images that were recycled and created by the Meccanomen in each of the different publications, before comparing and contrasting them. This research would help to reveal the various manifestations of Meccano that the Meccanomen developed in their individual clubs to satisfy their nostalgia. While these separate versions of Meccano are alluded to in the analysis of the Meccanomen's voices in Chapter Six, an analysis of how each club has developed would increase our understanding of fan- and enthusiast-cultures in relation to amateur science and engineering.

The exploration of the Meccanomen's voices and the enthusiasts from the Oral History of British Science (OHBS) archive at the British Library in Chapter Six alluded to the presence of the Meccanowomen. Despite producing a systematic research project to engage with the Meccano enthusiasts, the Meccanowomen remained an elusive group. However, this is part of a broader marginalisation of women engineering enthusiasts in both the community of Meccano users and in the wider literature. Specifically engaging with the Meccanowomen, and other women science and engineering enthusiasts (beginning with those members of the Women's Engineering Society) would be a useful priority for future research, as it would provide an alternative perspective to the traditional role of women and girls in relation to playful engineering and science, and celebrate their previously 'hidden' contributions.[728] The time-specific importance of this research increases each year, as the average member age in enthusiast clubs continues to climb. This reduces the voices of both the Meccanomen and Meccanowomen who grew up with Meccano and other engineering and scientific toys in the middle of the twentieth century. Chapter Six also alluded to the large number who perceived themselves to be amateur scientists and engineers; these voices would also provide a useful resource for those exploring the contrasting identities of amateur and professional scientists. Alongside these, the success of the 'participant historiographies' in Chapter Six is something for historians to test in other contexts, to learn more about composure and discomposure, and about the benefits of bringing together different historical methods, including oral history and public history with the history of science.

Chapter Seven detailed the processes of historically reproducing the original Meccano differential analyser as the Kent machine, and the 'shared authority' I encouraged from the Meccanomen and audiences to co-curate its public history, resulting in the Henwood-Lawrence machine. Future research on the Henwood-Lawrence machine could encompass and analyse the conflicts of authority that I experienced at each public demonstration of the machine (alongside the two that were focused on in the chapter). This would help to increase our understanding of how 'shared authority' changes the meanings of machines in a public context, which could also be usefully applied to museums. As the chapter also mentioned, the Science Museum has decided to collect the machine from me at the completion of this thesis, adding it to their collection. At the time of writing, my understanding is that their intention for the machine is for it to be used to demonstrate the principles of differential analysis,

[728] For further information on the Women's Engineering Society, refer to https://www.wes.org.uk/ [accessed 18 February 2020].

similar to Hartree's original use for the Trainbox object in 1947. However, an interesting piece of future research would be to return to the Henwood-Lawrence machine in a decade or two, analysing how it has been changed in the museum. This research could focus on comparing its journey with the Trainbox as a collected object during the same period, and whether the story of computing that the Henwood-Lawrence has been used to tell reflects the public history that was specifically co-curated for the machine.

5. Closing Thoughts

This thesis has demonstrated that the original Meccano differential analyser is a product of its assemblages. It established that the internal assemblages of the original differential analyser (the Meccano materiality and analogue computer instrumentality) change in accordance with the external assemblages to which they are attached (the wider stories of Meccano and the development of the 'analogue gap' in the history of computing). The deconstruction and reconstruction of these internal and external assemblages establish how the identities of the object have changed over time, both inside and outside of the Science Museum. It also demonstrated that these different identities are still visible in the Trainbox – despite being changed by the museum – if one knows where to look for them.

The two stories of the original differential analyser told in this thesis – as a Meccano model and an analogue computer – have had similar trajectories, with both being prominent before the Second World War and decreasing in visibility afterwards. The exploration of the original Meccano differential analyser in this thesis, along with the Henwood-Lawrence machine inspire a further analysis of these under-researched elements of our past and how they are treated in museums. Deconstructing the original Meccano differential analyser and the Trainbox, and reconstructing the Kent machine and co-curating it as the Henwood-Lawrence machine, has helped to close the gaps in many different areas of material culture, museum studies, public history, and oral history scholarship. These various approaches to the object demonstrate how we change and are changed by historical and scientific objects in different contexts, and highlight how a toy was used to briefly create the most powerful computing device in the UK.

Material Appendix One: Meccano

While this thesis represents a serious piece of scholarly work and the viva is a mechanism to reflect that, I also want both to reflect the playful nature of Meccano.

The enclosed Meccano sets can be used to build a variety of different objects. They have been included for you to build something from your imagination as you read the thesis. They will help to give you a physical understanding of Meccano pieces, which should provide useful context for many of the chapters in this thesis.

The version of this thesis submitted for examination included a Meccano set to help the examiners to get into the playful mindset that must have been required to build a computer from Meccano (play with Material Appendix 1). I would recommend anyone else reading this thesis to invest in their own sets of Meccano, or visit one of the Meccanomen meetings, listed at: http://internationalmeccanomen.org.uk/ism.html.

Appendix Two: Interview Questions

1. Please describe your first encounter with Meccano.
2. When did you first join a Meccano club, and which club was it?
3. Do you hold advanced-level qualifications (beyond A-Level)?
4. Would you consider yourself a scientist or engineer?
5. Do you have any other hobbies/interests outside of Meccano?
6. What benefits has Meccano brought to your life and career beyond enjoyment?
7. What skills have you learned from Meccano, and do you think these skills are missing in young people today?
8. Was there a 'golden age' of Meccano, and were you a part of it?
9. Was there a 'golden age' of engineering, and were you a part of it?
10. Do you think if more young people used Meccano today, it would benefit the national good of Britain?

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