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Faraday's notebooks: the active organization of creative science

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Faraday's notebooks constitute one of the largest and most revealing archives left to us by a major scientist. These records reveal a good deal of systematic invention and exploration of recording techniques by Faraday, work that reveals much about his thinking about science, as well as of the role of memory in general in scientific thinking.

Scientists are students—students of nature, to be sure, but, like all students, dependent for their success on the taking of notes. In even the most routine of scientific research, scientists must preserve external records of their work. Most externalize far more than just data, making records of their hypotheses, readings of the literature, wild speculations and the like. Thus, scientific diaries, laboratory notebooks, indeed the entire range of recording techniques, constitute an important topic for a full understanding of just what scientists do (Holmes 1987).

Michael Faraday has left us a richer documentary legacy of thought than exists for perhaps any other scientific figure in history. Faraday's daily laboratory notebooks, diaries and commonplace books, almost all of which were carefully bound by Faraday himself, and almost all of which are held in the Archives of the Royal Institution of Great Britain and the Institution of Electrical Engineers are a rich source for the historian. As a rough guess, he left us records of about 30 000 experiments, both successful and unsuccessful, as well as a large number of speculative idea books, bibliographies, indexes, scrap-books, etc etc. What is known as 'the' Diary has even been published (Martin 1932–6). Though only a part of the archival holdings, this work does cover most of his famous discoveries (and lots of lesser ones as well). But it is very much a laboratory diary, and thus gives a somewhat misleading picture of the whole. This paper will present a broader perspective, one that sheds light on the entire range of Faraday's records. In this way, we will be able to gain some insights into the uniquely creative mind of a genius.

Why are Faraday's records so extensive? In part, it is because Faraday was mistrustful of his own memory (see Williams 1965, pp 473, 491–501; Hare 1974). Faraday more than once repeated an experiment that he had earlier completed and apparently forgotten about, and his use of elaborate memory-retrieval devices (see below) makes a similar point.

Memory weaknesses aside, however, Faraday was very much part of a cultural tradition of ideas deriving from John Locke (1632–1704) that placed central importance on memory as an essential cognitive process in the acquisition of knowledge. In the Lockean theory of ideas, knowledge is built upon *stored* sensations and ideas: imagination, reason, and such things as Descartes' 'clear and distinct ideas' are built on the foundation of memory. Locke himself saw that this account had strong implications for the importance of memory aids. If memory was to be the foundation of knowledge, then the *weaknesses* of human memory—forgetting, distortion, the vagaries of the retrieval process—constituted serious problems. True knowledge needed accurate memories, and this required the use of accurate records.

Faraday derived his Lockean view of memory from Isaac Watts (1674–1748) whose *Improvement of the Mind* (1809/1741) was read by Faraday in 1809 and credited by him with 'having taught me to think'. It inspired Faraday's first surviving memory aid, the *Philosophical Miscellany* (Faraday 1809–10). His use of memory aids evolved subsequently during the course of his career, culminating, after 1831, in the mature recording and retrieval system that is described in the next section. It is worth noting that one important respect in which Faraday was *not* Lockean was in his reliance on the power of experiment. Neither

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Locke nor Watts discussed the difference between observation and experiment (i.e., observation of the consequences of a manipulation), Faraday, however, relied heavily on manipulative principles, on the ability to control a phenomenon as a foundation for knowledge (Gooding 1985, Tweney 1985, 1989, 1990).

Faraday's diaries, notebooks, etc

A 'bird's-eye' view of the surviving material reveals five broad categories: (*a*) Diaries proper, including 'the' Diary, (*b*) Idea Books, (*c*) Loose slips, (*d*) Retrieval sheets and (*e*) Work sheets. Surviving examples of the first category are found for nearly the whole of Faraday's career, the second category only for the 1820s, and most of the surviving examples of the last three categories from 1833 or later. From time to time, Faraday would include in a diary itself a section resembling one or another of the other categories.

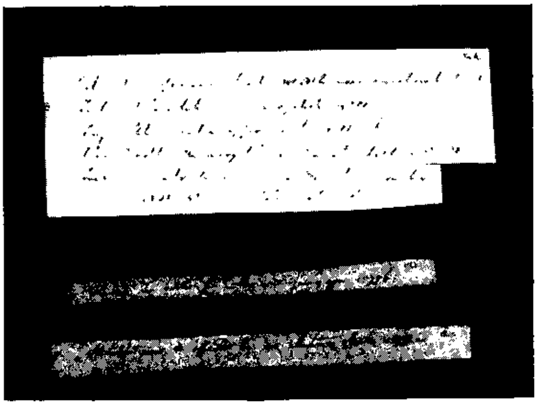
'The' Diary is a set of bound volumes primarily recording Faraday's laboratory activity after 1820, but also including miscellaneous observations, theoretical developments, speculations, etc. All entries except those in the first part (from September 1820 to 15 September 1832) are numbered sequentially from 1 (25 August 1832) to 16041 (6 March 1860). Faraday sometimes kept parallel diaries (as even the above dating suggests), including a series on applied researches conducted for Trinity House and the Royal Admiralty. However, his most important researches were apparently all recorded in the Diary proper, as part of the numbered series from 1831 onwards.

'Idea books' are records of speculations, possible experiments, theoretical musings and the like, and are generally present only for his early career, before 1830. The most important one, the *Chemical Notes, Hints, Suggestions and Objects of Pursuit* (Faraday 1822, soon to be republished in an edition edited by Tweney and Gooding 1991) contains a variety of speculative ideas, and seems to have been used by Faraday over a reasonably long period of time. Idea books were not kept in chronological order, entries were not dated, blank spaces were frequent, and there is evidence that Faraday altered some entries after, perhaps long after, they were written. In a number of cases, Faraday *crossed out* particular entries—this was rarely done in the diaries. Whereas diaries have a single 'growing edge', idea books may have multiple growing edges. Once the Diary proper was developed into a sequential, numbered record, idea books became scarcer and, when they do survive, are shorter, more narrow in focus, and unbound. Their function seems to have been largely usurped by the Diary itself and the other retrieval devices.

Faraday's retrieval devices, loose slips and sheets with one or a few lines of references, are very different in character from the bound diaries and idea books. Loose slips are generally small (about 12 by 100 mm, on average) and almost always contain only one line of writing (see figure 1). Retrieval sheets are generally foolscap size (343 × 432 mm) or half foolscap size (343 × 216 mm). They generally have multiple lines of entries (figure 2). The loose slips most often contain a brief descriptor followed by one or more references to Diary numbers, but sometimes they contain speculations, references to the literature or experiments to be tried. (The content of these tags resembles that in the earlier idea books). These slips played an important role in Faraday's problem-solving activity; there is evidence that he would sort and re-sort the slips on a particular topic, sometimes pasting up a group of them onto a sheet for further use (figure 3), and using them to organize the writing of his scientific papers.

The surviving retrieval sheets manifest a great variety of format, including the 'paste-ups' referred to above. One wonders what he might have achieved with a modern database manager! The pasted versions, in particular, appear to be the end-product of an active search for the right ordering of the entries. In the case of the unpasted versions, presumably no such search was needed, the ordering being either irrelevant to Faraday, transparently obvious to him, worked out on a prior occasion, or not yet established. But in all cases, it is evident that Faraday was actively seeking to impose order on his references to his

Figure 1. Examples of the loose slips (IEE Archives, Misc. Mss. SC2).



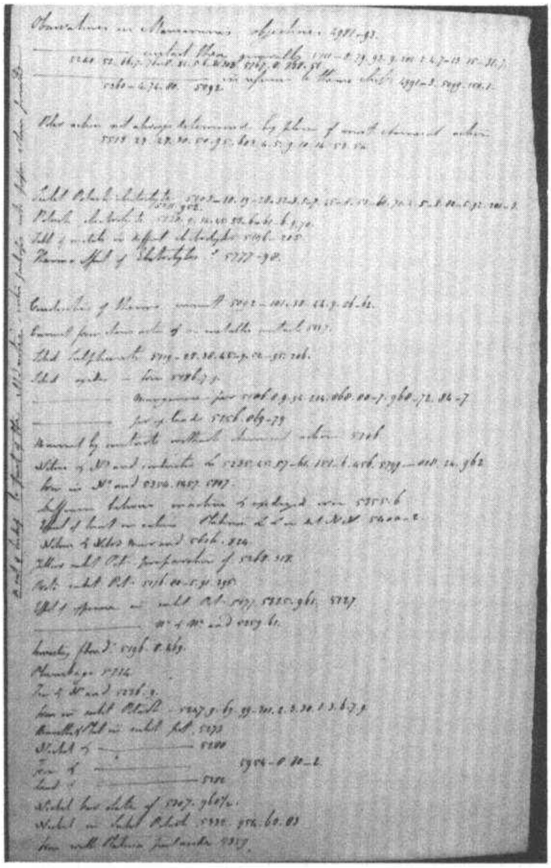


Figure 2. An example of a retrieval sheet (IEE Archives, Misc. Mss. SC2).

own Diary entries or on his speculative thinking. His use of the retrieval aids was a dynamic one.

Looking at the retrieval sheets once suggested a kind of experiment to me. I took one of the sheets and photocopied the relevant sections referred to in the Diary, pasted *these* up on long sheets, and tried to read the result, to see if I could get insights into what Faraday was after in making the retrieval sheet. Unfortunately, the result made little sense, even when it dealt with a part of the Diary that I was fairly familiar with. The reason is clear: Faraday didn't just need references to the particular facts recorded in the Diary; he needed *cues* to the entire context of his memories about the incidents in question. In fact, when I abandoned the long paste-ups that I had made and simply read the Diary in the order in which references were made, the whole made much more sense. My eye could pick up closely associated references in adjacent parts of the Diary, and these were helpful in reconstructing the context. How much richer this would have been for Faraday, for whom these adjacent 'reminders' would have been full of the concrete memories, images, emotions and so on of the original incident.

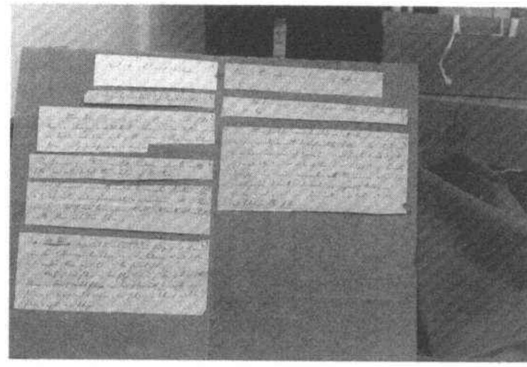


Figure 3. A 'paste-up' (IEE Archives, Misc. Mss. SC2).

Among the many types of retrieval sheets that survive, some stand out because they don't refer directly to the Diary itself. Instead, they seem to be indexes of indexes, or 'menus' to use a modern computerese term. These are striking because they suggest that Faraday used so many retrieval devices that he needed to organize these as well. Anyone who has lost a file on a hard disk will appreciate the need!

Constructing retrieval aids of the sort described above can be seen as analogous to an encoding process in which a retrieval cue (an index tag, say) is encoded in a physical form with an address to the full diary entry. Once the tag exists, it can be used in one of two ways. First, obviously, it can serve as a finding aid for the retrieval of specific diary entries. Second, and perhaps even more importantly, it can serve as a mnemonic cue useful in the structuring of diary-based knowledge. By sorting slips one can impose one or another organization on diary entries, and vary that organization in the service of other goals.

Development of the memory aids

So far, the discussion has focused on Faraday's use of retrieval aids in their mature form, i.e. after 1832. By looking at earlier records, however, it is possible to trace the evolution of Faraday's use of external memory aids. Faraday's earliest surviving notebook is the *Philosophical Miscellany* kept in 1809–10, which was used mainly to copy out interesting things Faraday had read. It contains an ordinary alphabetical index evidently prepared after the book was completed; while such an index is useful, note that it can only be prepared *after* all of the contents of the notebook have been entered.

In 1813 Faraday received a position as Humphry Davy's laboratory assistant and amanuensis. Part of his responsibility was to keep notes and to recopy laboratory records for Davy. The surviving notes of Davy are so chaotic and so disorganized that it is clear that Faraday had a good example before him of what *not* to do! But clearly it was also an opportunity for Faraday to gain practice in the keeping of records in general. Whatever his own failing, Davy knew this was important and, over time, entrusted Faraday with increasing responsibilities for record-keeping in the laboratory.

For his own use, Faraday kept a *Common-Place Book*, starting in 1816, which used a published copy of Locke's posthumous *Common-Place Book* (Locke 1800). This work contains several pages of instructions on how to set up the book to allow the retrieval of specific facts, through an alphabetical index, on any desired topic. The index was not, however, an ordinary one. Instead, it is a 'real-time' index scheme that grows as the notebook grows, and does not require a pre-existing set of keywords or index categories. The blank index scheme provided by Locke consisted of the 26 letters, each followed by lines for the five English vowels. Each time an entry is made in the notebook, it can be indexed by entering the page number under the appropriate first letter and first vowel. For example, Magnetism would be entered on 'M' and 'a', Electricity under 'E' and 'e', and so on. With this scheme, you can make an index that is constantly updated every time a new entry is made to the book. It is Faraday's first use of a dynamic retrieval scheme.

Faraday used the Common-Place Book to record interesting things read or heard in lectures, various observations and quotes, jokes he seems to have favoured (e.g., one entry reads, in its entirety, 'how to make any given cause produce any given effect . . . To do this you need only to Write a novel'.). Of particular interest is a description of Gregor von Feinagle's (1813) mnemonic memory scheme, which describes a variety of ways in which one's literal recall of facts could be enhanced, including a very specific 'Method of Loci'. In this ancient method, a particular room, very familiar to the user, is used to provide a fixed sequence of images. If a list is to be remembered each item in the list is imagined being placed in turn, in the 'mind's eye' at one of the locations. To recall the list, one can then 'walk around the room', picking the items off in sequence. With practice, this can be a highly effective aid. Feinagle recommends tailoring the method to a 'room of one's own', and Faraday did this, but in a way suggesting that he creatively expanded Feinagle's scheme. Instead of the linear ordering used by Feinagle, Faraday used three *overlapping* orderings distinguished by the modulus of a numbering scheme. Perhaps Faraday intended this to be used as a way of preventing separate sequences of remembered items from interfering with each other. The innovation represents a fairly sophisticated spatial twist on an old idea. Faraday in effect condensed three separate 'memory spaces' into one.

In 1820 Faraday began to keep a systematic laboratory diary ('Quarto Volume I' of 'the' Diary) which, as noted earlier, has been published (Martin 1932–6). Entries are dated but not numbered (except for a brief series in September 1821), and the date ordering is highly irregular. Faraday evidently wrote this book in sections, moving back and forth as the topic dictated. The book was kept from September 1820 to 17 December 1823, towards the end of which 'Quarto Volume II', bearing dates from 10 December 1823 to 1 October 1833 was started. This book is partly blank, suggesting that, as time went on, it was replaced by a better scheme.

Idea books seem to have been kept early during the same period (the 1820s and early 1830s), the most notable being the 1822 *Chemical Notes, Hints, Suggestions and Objects of Pursuit*. Organized by topic, with frequent blank spaces of various size, this book appears to have been in use at least until 1831. It contains a number of remarkable premonitions of his later discoveries (cf Tweney and Gooding 1991).

In 1831, in 'Folio Vol. I', we see the emergence of the numbered, chronological Diary that formed the core of the mature memory aid system described in the previous section. This book, in contrast to the earlier books, was bound by Faraday *after* it was written. Though it has been suggested that it was not a 'real-time' record (e.g. Agassi 1971), my belief is that it was kept on at least a *near*-daily schedule. For one thing, Faraday himself urged students to keep daily records (Faraday 1827, p 546). If the Diary does represent a 'fair copy' of (presumably lost) laboratory notes as such, then it seems likely, at the very least, that the copy is complete.

During 1831 Faraday began two numbering schemes, trying one from 2 February to 14 March (#'s 1 to 72) and one from '17 June and previous' (as he puts it) to 18 July (#'s 1 to 147). On 29 August Faraday began numbering once again. Entries #1 to 441 (i.e., from 29 August 1831 to 11 June 1832) deal solely with electricity and magnetism, and record his greatest discovery, that of electromagnetic induction on 29 August 1831. On 25 August 1832 he began at #1 yet again. This time, however, the sequence was continued nearly to the end of his life, #16041 being recorded on 6 March 1860. This unvarying numbered sequence had clear utility for Faraday, because it is only with such a fixed and unvarying address scheme that he could have used the wide variety of retrieval aids, loose slips, sheets and suchlike, that we know he used from the 1830s to the end.

Conclusions

It is clear that Faraday required and used a variety of *different* organizational principles to cover the same record of stored material. No single structure can represent his activity, which is why we see such a plethora of external aids. This also accounts for his use of slips, which can be sorted and re-sorted until the particular structure needed for a given purpose has been attained.

That Faraday's use of remembered material was a constructive process follows from the above. In developing his ideas and in preparing them for public presentation, Faraday worked and re-worked the structure of retrieved items, in effect constructing a larger whole from the separate bits and pieces. Notice that while the point of external memory aids is precisely to *prevent* change in what is remembered (i.e., the 'facts' retrieved must be unvarying), the same is not true of the organizational structure of the remembered material. It is frequently noted that remembering is an active process; what is less frequently noted is that the activity in question often involves a search for inter-item structure. A record such as Faraday has left us seems like an ideal place to study this issue.

Finally, and most speculatively, I believe the case-study sheds light on an aspect of the role of memory that is often slighted. When Faraday works actively to organize the information in his Diary, his goal is generally *not* that of organization for its own sake. The organization that he imposes is instead in the service of another kind of goal, namely, the imposition of order on his understanding of some physical process (see Cantor 1991). A good deal of his research sought to impose a particular kind of order on nature, one that was expressed in scientific laws involving forces (Tweney 1990). In the present context, we can see such a law as an extension and a generalization of the structure used to organize the 'facts' in retrieval. Searching for laws does represent, then, something like a search for semantic principles from episodic records. But in fact a scientific law goes beyond a semantic memory insofar as it stands for *all possible* memories. A law achieves this generally by virtue of its *generativity* (see Gooding and Tweney 1991). Having a law let Faraday thereafter ignore the specifics in the Diary, and the specifics of anyone else's diary as well. All such memories would have been *externalized* in the form of a simple expression. On this view, a scientific law is just one more manifestation of an external memory aid!

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