The Royal Society Corpus 6.0
Providing 300+ Years of Scientific Writing for Humanistic Study

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Abstract
We present a new, extended version of the Royal Society Corpus (RSC), a diachronic corpus of scientific English covering
300+ years of scientific writing (1665–1996). The corpus comprises 47,837 texts, primarily scientific articles, and is based on publications of
the Royal Society of London, mainly its Philosophical Transactions and Proceedings. The corpus has been built
on the basis of the FAIR principles and is freely available under a Creative Commons license, excluding copy-righted parts. We
provide information on how the corpus can be found, the file formats available for download as well as accessibility via a web-
based corpus query platform. We show a number of analytic tools that we have implemented for better usability and provide an example of use of the corpus for linguistic analysis as well as examples of subsequent, external uses of earlier releases. We place the RSC against the background of existing English diachronic/scientific corpora, elaborating on its value for linguistic and humanistic study.

Keywords: Corpus (Creation, Annotation, etc.), Digital Humanities, Language Modelling, Text Analytics

1. Introduction
We present the newest release of the Royal Society Corpus (RSC), a diachronic corpus of scientific English covering the period from 1665 until 1996. The corpus comprises 47,837 texts, mainly scientific articles, and is based on the Philosophical Transactions and Proceedings of the Royal Society of London. The corpus is made available under a Creative Commons license, excluding the recent decades, which are still under copyright.

We describe the origin of the data for the RSC, the processing pipeline and available annotation layers (Sections 2 & 3) and place it in the landscape of comparable corpora (Section 4). We provide several file formats for download, both plain text and XML, and we also host an installation of the corpus on our corpus query platform for easy access (Section 5). We conclude with a detailed example of application of the corpus and its accompanying infrastructure (Section 6) followed by a brief summary and outlook (Section 7).

2. Related Corpora and Own Previous Work
There are several diachronic corpora of written English that contain scientific texts but, to the best of our knowledge, there is no dedicated diachronic corpus of scientific English that comes with similarly good conditions of use as the RSC.

For example, the Corpus of Late Modern English Texts (CLMET) covers the period from 1710 to 1920 and comprises 333 texts from five different genres. De Smet et al. (2015) CLMET contains 34M words from British authors and is available under a Creative Commons license.

The Corpus of Historical American English (COHA) contains more than 400M words of historical English from the 1810s until the 2000s (Davies, 2010). COHA is balanced by genre and time with the following four genres: Fiction, Magazine, Newspaper, and Non-Fiction. Querying the corpus is free, but full-text access must be purchased.

The Scientific Text Corpus (SciTex) contains English scientific research articles from the 1970s and the early 2000s (Degaetano-Ortlieb et al., 2013). SciTex covers nine scientific disciplines and contains 34M tokens. Access to the corpus is limited due to copyright restrictions on the research articles.

ARCHER (A Representative Corpus of Historical English Registers; Biber et al., 1994; Yáñez-Bouza, 2011) is designed to contain 10 samples of 2k words each per 50-year period, language variety (British or American English), and genre. ARCHER-3.2 contains 12 genres, among them medicine and science, spanning the years 1600–1999. The complete ARCHER corpus has a size of about 3.3M words and is only accessible for members of the ARCHER consortium. For other users, there is restricted access to a query interface with a limited amount of downloads. The subcorpora belonging to the genres science and medicine are small compared to specialised corpora on scientific texts.

The Corpus of English Scientific Writing (Crespo-García and Moskowich, 2013) is a collection of text samples representing late Modern English scientific writing except medical texts. It covers the period between 1700 and 1900 and is comprised of eight subcorpora on different scientific disciplines (e.g. astronomy and philosophy), some of which are still under development (e.g. the subcorpora of life sciences and chemistry), each containing approximately 400k words and representing a variety of text types. Representativeness according to sociolinguistic criteria and balance within the corpus were important design criteria. The Coruña Corpus can be searched with the Coruña Corpus Tool (CCT).

The corpus of Middle English Medical Texts (EMEMT) contains 86 texts about medicine with 0.5M words from ca. 1375 to 1500. It is available on CD-ROM via a commercial publisher (Taavitsainen et al., 2005). It is diachronically succeeded by the corpus of Early Modern English Medical Texts (EMEMT) with ca. 450 texts and 2M words
from 1500 to 1700, which is also published as a CD-ROM (Taavitsainen et al., 2010). A third corpus in this series is the LMEMT (Late Modern English Medical Texts) covering the years 1700 to 1800 is now also available. Early English Books Online (EEBO) is a large collection of Early English printed books prepared by the Text Creation Partnership. EEBO Phase I is freely available and contains 750M words from more than 25k texts covering the years 1470–1699. EEBO Phase II aims at additional 45k books and extends the range of years to 1820. Access is currently restricted but a public release is announced for July 2020. It is currently available on subscription basis from Sketch Engine. There is no available genre annotation in the EEBO corpus.

Against this background, the RSC fills a gap in that it provides a coherent, diachronic corpus of scientific English covering the entire period of Late Modern English (LModE, ca. 1700–1900) as well as the transition periods at the beginning and the end of LModE. It has a fair size, has been processed according to current best practices (see Sections 3 and 4) and the larger part is made available according to the FAIR principles (Section 5). Given the role of the Royal Society in scientific publications, the RSC is not only highly relevant for diachronic linguistic analysis, see e.g. (Fettgen et al., 2017), Degaetano-Ortlieb and Teich, 2018, Degaetano-Ortlieb and Teich, 2019), but also to historical and cultural analysis, e.g. (Fyfe et al., 2015), Moxham and Fyfe, 2018).

Table 1 gives an overview of earlier versions (2.0 & 4.0) of the RSC as well as the new ones.

| Version   | Years      | # Texts | # Tokens     |
|-----------|------------|---------|--------------|
| RSC 2.0   | 1665–1869  | 9,813   | 35,311,790   |
| RSC 4.0   | 1665–1869  | 9,779   | 31,952,725   |
| RSC 6.0 Open | 1665–1920 | 17,520  | 78,605,737   |
| RSC 6.0 Full | 1665–1996 | 47,837  | 295,895,749  |

Table 1: History of RSC releases. Compared to previous releases, the current Open version covers 51 additional years.

3. Corpus Building

The corpus is built inspired by the principles of Agile Software Development (Cockburn, 2001), i.e. corpus preprocessing, corpus annotation and linguistic analysis are intertwined and repeated cyclically.

There are several processing steps, which are described in detail in (Kermes et al., 2016). In the beginning, due to format inconsistencies, we had to manually edit some of the raw files which we received from JSTOR and the Royal Society. This was only done once and the remaining processing steps are fully automated. As a first step, we filter texts written in languages other than English such as papers in Latin in the earlier Philosophical Transactions. We use langid.py (Lui and Baldwin, 2012) for language identification and we only keep texts that are considered English with absolute certainty.

While versions 2.0 and 4.0 used a pattern-based OCR post-correction with high precision and low recall, version 6.0 integrates the Noisy-Channel Spell Checker by (Klaus et al., 2019) for a better recall and F-score at the cost of some loss in precision.

3.1. Origin and Content of Texts

Versions 2.0 and 4.0, which both cover 1665–1869, are fully based on data obtained from JSTOR. Version 6.0 contains additional data, which we received from the Royal Society. In version 6.0, texts from 1665–1869 are still based on JSTOR data with improved processing as described above, whereas later texts are based on the new data from the Royal Society. We chose this approach in order to maintain comparability with analyses based on earlier releases of the corpus.

The texts in the corpus cover a wide range of areas from both the physical sciences and the biological sciences. During the three centuries covered by the corpus, scientific discourse formed as a discipline and underwent considerable changes. Hence, more recent articles can be classified into modern fields of study without difficulty, e.g. physics, chemistry, mathematics, engineering or biology. However, many of the early texts cannot be described by these modern categories.

3.2. Statistics

In total, the corpus contains 295,895,749 tokens in 47,837 texts. Of these, 17,520 texts and 78,605,737 tokens are part of the Open release. Table 2 shows a detailed overview of the number of texts and tokens over time. As can be seen, the number of available texts and tokens increases exponentially.

| Years   | # Texts | # Tokens |
|---------|---------|----------|
| 1665–1899 | 1,325  | 2,582,856 |
| 1700–1799 | 1,686  | 3,414,795 |
| 1750–1799 | 1,819  | 6,342,489 |
| 1800–1849 | 2,774  | 9,112,274 |
| 1850–1899 | 6,754  | 36,993,412 |
| 1900–1949 | 10,011 | 65,431,384 |
| 1950–1996 | 23,468 | 172,018,539 |

Table 2: Size of the Royal Society Corpus over time.

4. Metadata and Annotations

4.1. Subcorpora and Texts

Texts in the RSC are classified by time periods of different granularity (year, decade, 50 years, century). All texts are annotated with their original metadata from the Royal Society whenever possible. For a small fraction of texts, if we could not establish a correspondence between their JSTOR ID and the DOI from the Royal Society, the original JSTOR metadata are used.
For example, apart from author and time of publication, we have information on text types. JSTOR provides four text types (book review, article, miscellaneous, and obituary), whereas the data from the Royal Society have a more fine-grained classification including abstract, appendix, article, bill-of-mortality, biography, book-review, lecture, report.

![Figure 1: Average number of authors per text over time.](image)

We also provide some statistical data on the texts, such as the number of tokens and sentences per text. For better usability, we added references to other resources, such as links to the full-text PDFs of the original articles on JSTOR and the Royal Society journal archive based on their DOIs. We also inserted links between texts and abstracts when such a relation could be determined. See Table 2 for an overview of all text attributes including proportions of coverage (some documents have missing metadata).

On the basis of the metadata, subcorpora can be built dynamically or they can be used directly in our corpus search (see Section 6). Furthermore, the metadata can be useful on their own, e.g. to explore writing/publication practice over time. See, for example, Figure 1 showing the diachronic development of multiple authorship over time.

### 4.2. Sentences and Tokens

As attributes of sentences we encode a running ID (within a document/text) and the number of tokens they contain. Each token is annotated as word (normalized form), original word form (historical spelling), lemma and part-of-speech. For part-of-speech tagging we use TreeTagger (Schmid, 1994, Schmid, 1995) and the Penn Treebank Tagset (Santorini, 1990) with some minor modifications.

For an analysis of part-of-speech tagging performance on a separate language models on the whole corpus (srp) and the Penn Treebank Tagset (Santorini, 1990) with some minor modifications. For an analysis of part-of-speech tagging performance on a previous version of the corpus see (Knappen et al., 2017). Since the newly added text material is closer to present-day language, no particular tagging problems arise.

### 4.3. Surprisal Annotation

As a special feature, we provide information on the (average) surprisal of words. Average surprisal (Kermes and Teich, 2017) is a measure of the amount of information transmitted by a linguistic unit (e.g. word or part-of-speech), averaged over all its instances (e.g. in a given time period): 

\[
AvS(token) = \frac{1}{|token|} \sum_{i} -\log_2 p(token|context_i)
\]

Here context refers to an ngram context of three previous words or parts-of-speech.

Diachronically, it is interesting to observe whether certain kinds of words become more or less informative on average. For example, lexical words carry more information on average than function words. In the RSC, we find that the frequency of nouns compared to verbs increases steadily over time (see Figure 2, indicating a shift towards a more nominal style. In general language, in contrast, no such change in frequency occurs, observed on the basis of the Corpus of Late Modern English. However, inspecting surprisal on nouns vs. verbs, we find that it stays fairly stable over time (see Figure 3) for both corpora. Interestingly, both nouns and verbs show higher mean surprisal in CLMET.

Surprisal is annotated into the corpus and calculated with separate language models on the whole corpus (srp), individual documents (doc), 50-year periods (s50) and decades (s10). See Table 3 for a list of all provided attributes.

For better usability we also provide an interactive visualization of surprisal scores (Fischer et al., 2017). In the visualization, words are scaled based on their surprisal values. See Figure 4 for an example.

Another perspective provided on the corpus is relative entropy (Kullback-Leibler Divergence; KLD) across sub-
Figure 2: Ratio of nouns and verbs in the RSC and CLMET over time. The usage of nouns increases steadily in the RSC.

Figure 3: Surprisal of nouns and verbs over time in the RSC and CLMET.

corpora (e.g. 50-year periods). KLD is an asymmetric information-theoretic measure for the comparison of probability distributions, measuring the additional bits needed for encoding when a non-optimal code is used. Applied to diachronic analysis, KLD gives us an indication of the linguistic differences between time periods.

Again, for better usability, an interactive visualization is provided (Fankhauser et al., 2014a, Fankhauser et al., 2014b), see Figure 3 for an example. The heat map on the left shows overall KL divergence between subcorpora (green=low, red=high). The word clouds in the middle and on the right show the most typical words of a given time period where color encodes relative frequency (blue=low, red=high) and size shows the contribution to the overall divergence. Both size and color are scaled logarithmically. The visualization is interactive and the words are linked to an installation of a web-based corpus analysis tool (CQPweb) (Hardie, 2012) based on the Corpus Query Processor. See Section 6 for a detailed example of analysis using the KLD visualization together with CQPweb.

5. Access and Usage

5.1. FAIR Principles

The RSC is designed and built according to the FAIR data principles (Wilkinson et al., 2016). It is hosted at the CLARIN-D repository at Saarland University and findable by a persistent and globally unique identifier, in our case a handle provided by the EPIC consortium. The RSC is described by rich CMDI (Broeder et al., 2011) metadata with a link to the landing page of the corpus. The metadata are indexed and searchable by the CLARIN Virtual Language Observatory (Van Uytvanck et al., 2012).

The Royal Society Corpus 6.0 Open is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. We provide files in several common formats (see Section 5.2). Furthermore, there are multiple options for searching the corpus online (see Section 5.3).

5.2. Download

The RSC can be downloaded in several formats. Our default format, which contains all available metadata, is

| Attribute | Description |
|-----------|-------------|
| word      | Normalized word form (VARD) |
| pos       | Part-of-speech tag |
| lemma     | Lemma, according to TreeTagger |
| orig      | Original word form |
| srp       | Corpus surprisal |
| srp_avg   | AvS on corpus |
| srpRnd    | Corpus surprisal (rounded) |
| srpAvgRnd | AvS on corpus (rounded) |
| doc       | Document surprisal |
| docAvg    | AvS on document |
| docAvgRnd | Document surprisal (rounded) |
| docAvgRnd | AvS on document (rounded) |
| s50       | Surprisal on 50-year periods |
| s50Avg    | AvS on 50-year periods |
| s50Rnd    | Surprisal on 50-year periods (rounded) |
| s50AvgRnd | AvS on 50-year periods (rounded) |
| s10       | Surprisal on decades |
| s10Avg    | AvS on decades |
| s10Rnd    | Surprisal on decades (rounded) |
| s10AvgRnd | AvS on decades (rounded) |

Table 4: Positional attributes in the RSC. word, pos and lemma are based on TreeTagger output. orig is the word form before normalization. Surprisal and average surprisal (AvS) are also provided as integers (_rnd).
5.4. External Subsequent Use

The Jena Semantic Explorer (JeSeMe) \cite{Hellrich2017,Hellrich2018} uses the RSC 2.0 as one of its underlying corpora. With JeSeMe, users can interactively explore similar words, word emotion, typical context, and word frequencies for lemmata.

A study on diachronic word embeddings on the RSC was undertaken by \cite{Fankhauser2017} and an interactive visualization of the results is available at Leibniz Institut für Deutsche Sprache (IDS) in Mannheim\footnote{http://corpora.ids-mannheim.de/diaviz/royalsociety.html}. RSC 2.0 is also included in DiaCollo\footnote{https://corpora.clarin-d.unil-aarland.de/cqweb/} maintained at Berlin-Brandenburgische Akademie der Wissenschaften (BBAW), which can be used for the extraction of diachronic collocations.

6. Sample Analysis: From KLD to Concordance

KLD provides a useful starting point for the analysis of linguistic similarities and differences between different time periods in the corpus data, helping the analyst to detect distinctive features. The eco-system around the RSC provides the user with various options for exploring candidate features further, e.g., by using CQPWeb queries for concordancing, collocations, distributional data, frequency lists...
and the possibility to investigate larger textual patterns and lexical and grammatical contexts in which distinctive items occur.

In this section we briefly exemplify some salient differences between the first and the most recent 50-year period in the RSC (1665–1699, 1950–1996) illustrated by examples from the word cloud visualization (see Figure 5) highlighting important words which contribute distinctively to the differences between the two time periods under consideration.

The differences between early and contemporary scientific articles are profound and the data confirm what we would expect with regard to the development of English scientific writing (cf. for instance (Atkinson, 1999) [Gross et al., 2002] [Biber and Gray, 2010]). The scientific paper has evolved from a narrative form with some typical coordinate and subordinate conjunctions (and, or, but), relative pronouns (which) as indicators of a distinctive use of clause complexes and lower lexical density and less compressed syntactic structures than in the more recent data. Negation markers and contrastive conjunctions (not, yet, but) are typical for the argumentative structure of earlier texts. Additionally, personal pronouns indicate that these earlier texts were characterized by rather explicit interaction between writer and reader (my, you), references to other individual (male) scientists (he) and the use of long coreference chains and hence a low frequency of new discourse referents within texts (it, them, their). The following passage from the 1680s illustrates these typical features of early scientific discourse practices well. Words that occur in the KLD visualization (see Figure 5, right) are highlighted in boldface.

(1) [..] my Reason in short is this: whatever is of sufficient Power to raise the minute Particles of a Heavy Body in a light Fluid, is certainly a sufficient cause to keep them in that state: now my Supposition may give some account of this; what my Brother says, never can; for he must necessarily suppose them first raised; and then he gives the reason of their not sinking: Whereas it is not to be questioned but that that Force which raised them, is the same that keeps them from falling to the bottom. (RSC, W. Molyneux, 1686, RSC ID: 101846, DOI: 10.1098/rstl.16860015)

The modern texts have a highly standardized article structure and content-focused, compressed structures.

As we can already conclude from the KLD visualizations, the period until 1700 was characterized by few specific content words, but numerous particular function words comprising coordinate and subordinate conjunctions (and, or, but), relative pronouns (which) as indicators of a distinctive use of clause complexes and lower lexical density and less compressed syntactic structures than in the more recent data. Negation markers and contrastive conjunctions (not, yet, but) are typical for the argumentative structure of earlier texts. Additionally, personal pronouns indicate that these earlier texts were characterized by rather explicit interaction between writer and reader (my, you), references to other individual (male) scientists (he) and the use of long coreference chains and hence a low frequency of new discourse referents within texts (it, them, their). The following passage from the 1680s illustrates these typical features of early scientific discourse practices well. Words that occur in the KLD visualization (see Figure 5, right) are highlighted in boldface.

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The modern texts have a highly standardized article structure with particular sections (e.g., results, preferably illustrated with figures). Quantitative research methods and means of expressing information symbolically are distinctive for modern articles as indicated, for instance, by nouns referring to general mathematical and scientific expressions such as measurements, data, values, and single letters used as abbreviations, e.g., for units, or as variables in formula and mathematical laws. The visualization also reflects the higher thematic specialization of modern scientific journals as we find specific nouns related to the physical and the life sciences (energy, cell, cells). Prepositions suggest a distinctive use of phrasal post-modifiers (in, for, on) within noun phrases. The verb form is could be an indicator for passive use and the importance of linking verbs in the sentence structure. The following passage from an article from the 1960s exemplifies these features that make modern texts quite distinct from historical ones. It is rich in independent clauses with a high frequency of nominal content words and pre- or postmodified noun phrases. Again, words that occur in the visualization (see Figure 5, middle) are highlighted.

(2) The energy threshold for detection of γ-rays was ∼ 30 GeV. Curves of constant energy in the laboratory systems are included. Figure 89 shows the results of some of the measurements. Each γ-ray is represented by a point at the appropriate co-ordinate. (RSC, P. H. Fowler, D. H. Perkins, 1964, RSC ID: rspa.1964.0070, DOI: 10.1098/rspa.1964.0070)

To be able to check in detail the items that are marked as distinctive by KLD, words in the cloud are linked to a CQPweb representation of the corpus, which can be queried by clicking on a word of interest. In CQP(web), more detailed queries can be formulated allowing to further inspect results. Furthermore, query results can be sorted, categorized and downloaded for further analysis as plain-text tables with information on metadata and linguistic annotations.

Figures 6, 7 & 8 show examples from a concordance, a frequency breakdown and a distribution table of nouns followed by a form of BE and a passive verb, a grammatical pattern that has become increasingly important over time in the corpus. As illustrated, the RSC on CQPweb allows users to perform various types of sophisticated corpus queries via the web interface and to extract and visualize the results in different ways. Concordances of particular patterns as shown above can be used in the classroom or for linguistic research in order to go beyond information currently available in other types of resources.

7. Summary

We have presented a new, extended release of the Royal Society Corpus (RSC), now covering all publications from the Royal Society of London from 1665 to 1996. We have shown that the RSC fills a gap in the landscape of diachronic, scientific corpora of English (Section 2). Given the role of the Royal Society in scientific publications, the RSC is highly relevant not only for linguistics but also for historical and cultural analysis. The corpus has rich metadata and has been linguistically processed according to best practices. The larger part of the corpus is open and distributed in several formats commonly used by computational and corpus linguists as well as digital humanists. Beyond this, we provide several web services to explore and analyze the corpus that are also freely accessible, such as visualization of differences across time periods on the basis of relative entropy and surprisal.

In our ongoing work, we are enhancing our metadata, e.g. by providing information on disciplines (approximated by topic models) or marking-up the individual authors of texts. This will allow more fine-grained analysis of the linguistic development of disciplines as well as detecting trends due to authors’ styles.
Figure 6: CQPweb: Concordance of nouns followed by a form of BE and a passive verb.

Figure 7: CQPweb: Frequency breakdown of most frequent noun + BE + passive verb sequences.

Figure 8: CQPweb: Distribution of nouns followed by a form of BE and a passive verb across time.

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