https://doi.org/10.51408/issi2025_063

How Can Citation Context Information Enrich Reference Publication Year Spectroscopy? A Case Study in Quantum Computing

Thomas Scheidsteger[1], Robin Haunschild[2], Lutz Bornmann[3]

[1]*t.scheidsteger@fkf.mpg.de*, [2]*r.haunschild@fkf.mpg.de*
IVS-CPT, Max Planck Institute for Solid State Research, Heisenbergstr. 1,
D-70569 Stuttgart (Germany)

[3]*l.bornmann@fkf.mpg.de, lutz.bornmann@gv.mpg.de*
IVS-CPT, Max Planck Institute for Solid State Research, Heisenbergstr. 1,
D-70569 Stuttgart (Germany)
Science Policy and Strategy Department, Administrative Headquarters of the Max Planck Society,
Hofgartenstr. 8, D-80539 Munich (Germany)

Abstract

Reference Publication Year Spectroscopy (RPYS) is an established bibliometric method for historical investigations of research fields based on an analysis of cited references. In this study, we propose to extend RPYS by the consideration of citation context information (CCI, location of citations in normalized sections and functions of cited papers for the citing author) to classify cited publications with respect to its specific relevance for a field. The study is based on publication metadata from the Web of Science (WoS, Clarivate). We explored the usefulness of CCI for RPYS by using exemplary publication data from the research field of quantum computing. The results show that the extension of RPYS by CCI enables more detailed analyses of cited papers (references) revealing their specific relevance for the field. The main limitation of the proposed extension is the lack of CCI data for many (older) citing publications in the WoS.

Introduction

Reference Publication Year Spectroscopy (RPYS) is an established bibliometric method for historical investigations of research fields (Bornmann & Marx, 2013; Marx, 2021). The method is not based on a times cited analysis (as most bibliometric studies), but on an analysis of cited references. In the first step of the analysis, a field-specific publication set is determined (in the Web of Science, WoS, Clarivate) such as publications dealing with quantum computing. In the second step, the cited references of these publications are analyzed with regard to the number of cited references (CRs) in each reference publication year (RPY). A plot (spectrogram) of the number of CRs against RPYs reveals peaks (RPYs including more CRs than in the neighboring RPYs) where historical roots of the field can be mostly found. RPYS can be performed by using the Java-based program Cited References Explorer (CRExplorer, https://crexplorer.net/, Thor, Bornmann, & Haunschild, 2018; Thor, Marx, Leydesdorff, & Bornmann, 2016). Since the introduction of the RPYS and the CRExplorer, more than 70 papers have been published using the method and/or the program (date of search in the WoS: January 2025). Some extensions of the initially proposed RPYS method have also been published. For example, Bornmann, Haunschild, and Marx (2023) proposed to analyze affiliation data of the CRs to identify most referenced researchers, institutions, and countries. Ballandonne and Cersosimo (2021) introduced methods for supporting the identification of peaks in the spectrogram.

Another extension which we are going to explore in the present study is the consideration of citation context information (CCI) to classify the CRs (under the peaks) with respect to their importance further on, i.e., going beyond simple counting of occurrences. Important historical papers for a field may be extensively discussed in the field-specific citing papers which can be detected by CCI. CCI has been provided in the WoS for papers published from around 2019 onwards (Clarivate, 2022). Especially two kinds of CCI are interesting for determining importance: (1) the section of a paper according to the Introduction, Methods, Results, and Discussion (IMRaD) scheme in which a referenced paper can be found (Sollaci & Pereira, 2004), and (2) the function a referenced paper may have for the citing author (Clarivate, 2024). For example, some papers are cited only as background information in the Introduction section of a citing paper; other referenced papers are discussed in depth in the Discussion section. Since the beginning of using citations for analyzing science processes, the context of citations in publications and motivations for citing have been analyzed. Overviews of the many studies published over decades of research can be found in Bornmann and Daniel (2008) and Tahamtan and Bornmann (2019). Tahamtan and Bornmann (2019) conclude that "citing motivation is a multi-dimensional phenomenon, and scholars cite the literature for a variety of scientific and non-scientific reasons" (p. 1675).

To explore the usefulness of CCI for extending RPYS, we made a case study in the emerging research field of quantum computing. We build upon the results of Scheidsteger, Haunschild, and Ettl (2022) who performed an RPYS analysis of a publication set (citing papers) over the years 1980 to 2020 in the broader research field of quantum technology. They separated the field into four subfields: quantum metrology, quantum information, quantum communication, and quantum computing. For this case study, the subfield quantum computing (Q COMP) was selected with the largest share of papers in the whole quantum technology dataset (Scheidsteger, Haunschild, Bornmann, & Ettl, 2021). Another reason for selecting Q COMP in this study was the expectation that a large share of citing papers would be fairly recent (because of Q COMP's rapid growth). Recent publications increase the chance of available CCI in the WoS.

Using the Q COMP dataset, the following research questions have been targeted in this study:

RQ1: In which sections are cited references in the Q COMP publications primarily included and with which functions?

RQ2: Is CCI useful and suitable to enrich RPYS?

Data and Methods

Web of Science citation context data

We used an April 2024 snapshot of the WoS that includes the Science Citation Index - Expanded (SCI-E), the Social Sciences Citation Index (SSCI), the Conference

Proceedings Citation Index - Science (CPCI-S), the Conference Proceedings Citation Index - Social Science & Humanities (CPCI-SSH), and the Arts and Humanities Citation Index (AHCI). The snapshot is licensed through, and made available by, the German Kompetenznetzwerk Bibliometrie (Schmidt et al., 2024). CCI is available in the WoS since 2021 on a large scale as annotations of in-text references (from now on called "citation instances" or "citation occurrences" in this paper) that indicate why an author may have cited them. These new data are called "Enriched Cited References" by Clarivate and include (1) a numeric value between 0.0 and 1.0 for the relative position of the reference in the text of a paper, (2) the original section title and a section title that is normalized according to the IMRaD structure (Sollaci & Pereira, 2004), as well as (3) possible functions of citations. Clarivate developed a classification scheme with five functions inferred by using machine learning methods. Clarivate (2022) describes the functions as follows:

- "**Background**—previously published research that orients the current study within a scholarly area.
- **Basis**—references that report the data sets, methods, concepts, and ideas that the author is using for her work directly or on which the author bases her work.
- **Discuss**—references mentioned because the current study is going into a more detailed discussion.
- **Support**—references which the current study reports to have similar results to. This may also refer to similarities in methodology or in some cases replication of results.
- **Differ**—references which the current study reports to have differing results to. This may also refer to differences in methodology or differences in sample sizes, affecting results" (p. 1).

In the present case study, we focus on the normalized section title and the citation functions to enrich RPYS.

Table 1 shows the availability of CCI in our WoS snapshot from April 2024. We have counted for each year (1) the number of distinct papers citing a publication inside our WoS snapshot, (2) the subset of (1) with CCI, and (3) the respective percentages. We show the most recent years from 2017 onwards where the share of citing papers with CCI is above 0.1%.

Table 1. Numbers of distinct papers citing papers from our WoS snapshot in total and restricted to those with CCI as well as their respective shares over the publication years 2017 to 2024.

Publication year	*Number of citing papers*	*Number of citing papers with CCI*	*Share of citing papers with CCI*
2017	2,159,399	3,166	0.15%
2018	2,255,973	9,575	0.42%
2019	2,356,928	109,927	4.66%
2020	2,460,656	416,043	16.91%
2021	2,628,144	975,457	37.12%
2022	2,685,716	1,148,183	42.75%
2023	2,594,737	1,260,628	48.58%
2024	814,416	492,040	60.42%

Publication sets

This study is based on a dataset used by Scheidsteger, et al. (2022) who analyzed the historical roots of quantum computing using 26,650 citing papers until 2020 that had been retrieved by applying the following WoS query, see section 3.3.4 in Scheidsteger, et al. (2021): ts=("quantum hardware" OR "quantum device*" OR "quantum circuit" OR "quantum processor*" OR "quantum register*") OR ts=("quantum software" OR "quantum cod*" OR "quantum program*") OR ts=("quantum simulat*" AND (qubit* OR "quantum bit*" OR "quantum comput*") OR "quantum simulator*") OR (ts="quantum simulat*" AND wc=("quantum science technology" OR "computer science theory methods")) OR ts="quantum algorithm*" OR ts=("quantum comput*" OR "quantum supremacy" OR "quantum error correction" OR "quantum annealer" OR (quantum NEAR/2 (automata OR automaton)) OR "quantum clon* machine*").

Scheidsteger, et al. (2022) restricted the set of cited papers to those 4,459 CRs that were cited at least 25 times in the dataset of citing papers. They identified 42 seminal papers within this cited paper set. The three most-cited papers were: (1) The original idea of quantum computing from a talk on ”Simulating physics with computers” given by R. P. Feynman in 1981 was published in Feynman (1982). The paper received 1,586 citations in the dataset used by Scheidsteger, et al. (2022). (2) In a conference contribution, Peter Shor presented the first examples of quantum algorithms with a highly practical usefulness (Shor (1994) received 2,176 citations) (3) which he later was able to prove as to be polynomial-time algorithms and therefore exponentially faster than any classical algorithm (Shor, 1997). This conference contribution received 1,581 citations.

Of the 4,459 CRs in the research area of Q COMP, a subset of 3,992 could be retrieved from our WoS snapshot of April 2024. Of the 42 cited seminal papers, a subset of 38 could be retrieved from this snapshot. Since the dataset used by Scheidsteger, et al. (2022) included citing papers only until 2020, we additionally considered the more recent citing publications indexed in the WoS snapshot of April 2024. This extension is due to the recent availability of CCI in WoS as documented in Table 1. To align the selection of the additional citing papers with the focus of the original RPYS analysis by Scheidsteger, et al. (2022), we took the 3,992 cited papers of Q COMP and retrieved all citing papers with CCI from the April 2024 snapshot. The resulting dataset was restricted to Q COMP-related papers by their intersection with the outcome of the above mentioned search query in the WoS online version. Of the 3,992 CRs, 3,616 papers have been cited in 5,520 citing papers with CCI amounting to a total of 72,242 citation instances. The 38 seminal papers have been cited in 2,360 citing papers with 6,427 citation instances.

Table 2 shows the annual distribution of the 38 cited seminal papers together with the number of distinct citing papers and the total number of citation instances for which Clarivate provides CCI.

Table 2. Distribution of seminal papers of Q COMP, of their citing papers and of the CCI instances in WoS over the publication years of the cited papers.

Publication year of cited seminal papers	*Number of cited seminal papers*	*Number of citing papers with CCI*	*Number of citation instances*
1982	3	402	652
1985	1	126	188
1986	1	40	50
1989	1	30	34
1991	1	90	111
1992	2	161	263
1993	1	139	235
1994	2	539	1,010
1995	3	318	471
1996	3	173	356
1997	5	593	1,184
1998	2	136	194
1999	1	32	37
2000	1	76	135
2001	2	185	283
2003	1	133	241
2005	5	287	494
2012	2	247	399
2014	1	62	90

Table 3 shows the annual distribution of the number of papers citing the 38 seminal papers together with the number of associated citation instances. In 2017, for example, four seminal papers have been cited five times in four distinct citing papers (with CCI). Table 3 shows especially in recent years a substantial number of citation instances (starting in 2019 with nearly 100). The results thereby mirror the overall availability of CCI in the WoS as reported in Table 1.

Table 3. Distribution of papers citing the 38 seminal papers of Q COMP and of the CCI instances in WoS over the publication years of the citing papers.

Publication year of citing papers with CCI	*Number of cited seminal papers*	*Number of citing papers with CCI*	*Number of citation instances*
2008	1	1	4
2013	2	1	7
2014	1	1	2
2016	1	1	1
2017	4	4	5
2018	8	5	10
2019	27	26	98
2020	37	196	508
2021	38	498	1,379
2022	38	636	1,815
2023	38	730	1,909
2024	37	261	689

Results

Distribution of citation instances across normalized sections and citation functions

RQ1 refers to the question in which sections cited references are primarily included and with which functions. Table 4 shows the distributions of normalized sections for both cited paper sets used in this study. In both cases, the Introduction section is by far the most frequent section containing citation instances but by more than six percentage points less so for all cited papers compared to the cited seminal papers. The results also show a doubling of the shares in the Results and Methods sections, respectively, as well as an increase in the Discussion section in the case of all cited papers compared to the seminal papers.

Table 4. Distribution of normalized sections across the citation instances in papers citing the 38 seminal papers of Q COMP (total number: 6,427) and all cited papers of Q COMP (total number: 72,242).

Normalized section	*#Occ. for cited seminal papers*	*%Occ. for cited seminal papers*	*#Occ. for all cited papers*	*%Occ. for all cited papers*
Introduction	5,556	86.4	57,895	80.1
Methods	120	1.9	2,656	3.7
Results	165	2.6	3,908	5.4
Discussion	283	4.4	4,396	6.1
Not classified	303	4.7	3,387	4.7

Notes: Occ. = citation occurrence

Table 5 shows the distributions of citation functions for both sets of cited papers. In both sets, the function Background is by far the most frequent function but by about six percentage points less so for all cited papers compared to the cited seminal papers. The results are reversed for the functions Basis and Discuss: The percentages of these functions are lower for cited seminal papers than for all cited papers.

Table 5. Distribution of citation functions across the citation instances in papers citing the 38 seminal papers of Q COMP (total number 6,427) and all cited papers of Q COMP (ttal number 72,242).

Citation function	*#Occ. for cited seminal papers*	*%Occ. for cited seminal papers*	*#Occ. for all cited papers*	*%Occ. for all cited papers*
Background	5,187	80.71	53,800	74.47
Basis	454	7.06	7,081	9.80
Support	3	0.05	206	0.29
Discuss	783	12.18	11,119	15.39
Differ	0	0.0	36	0.05

Notes: Occ. = citation occurrence

Table 4 and Table 5 reveal similar trends: Compared to all cited papers, cited seminal papers tend to be more often considered as background information in introductory sections and less often considered as sources of foundational methods (for state-of-the-art research). This observation holds at least for the years from 2019 onwards where the vast majority of CCI can be found.

RPYS enriched by normalized sections and citation functions

RQ2 concerns the usefulness of CCI for RPYS. In order to explore this question, we grouped the citation instances of the 38 cited seminal papers by their RPY, plotted the respective shares of the classes (normalized sections or citation functions) as stacked bar plots in Figure 1 and Figure 2 (resembling the RPYS spectrograms known from the RPYS analysis), and examined their peak structure (with respect to normalized sections and citation functions). The colors in the figures were chosen in a way that they visually connect normalized section titles with their most suitable counter parts in the citation functions such as Introduction with Background.

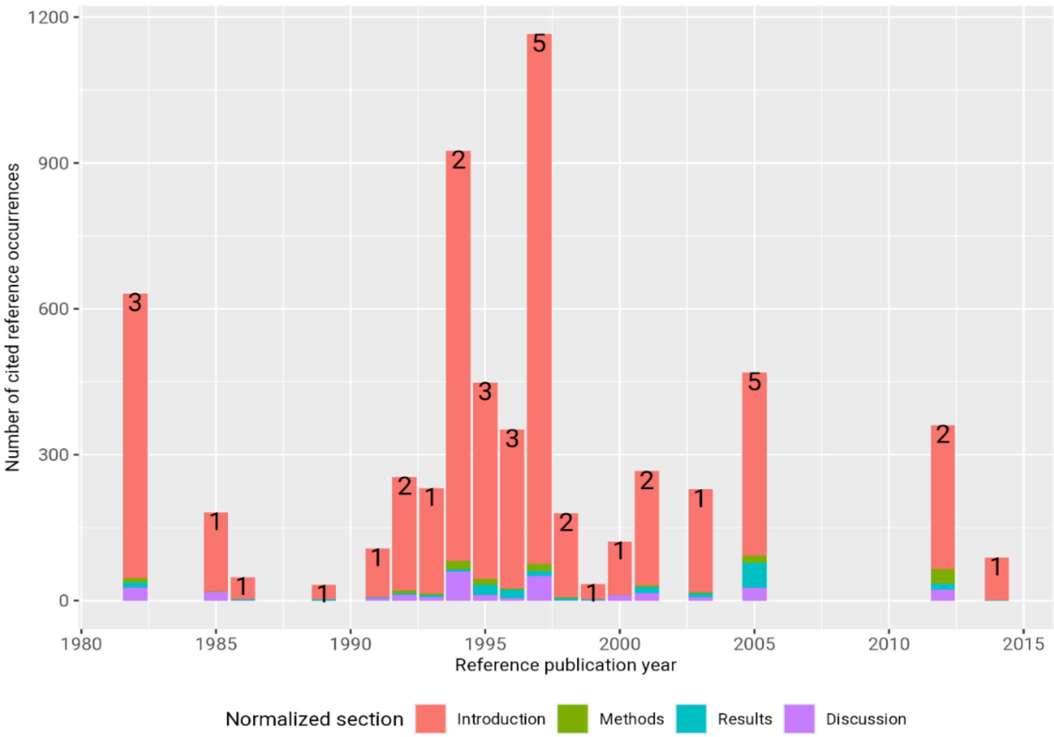

Figure 1. Annual numbers of normalized sections associated with the citation instances for the 38 cited seminal papers of Q COMP. The number mentioned in each bar is the number of cited seminal papers in the respective RPY.

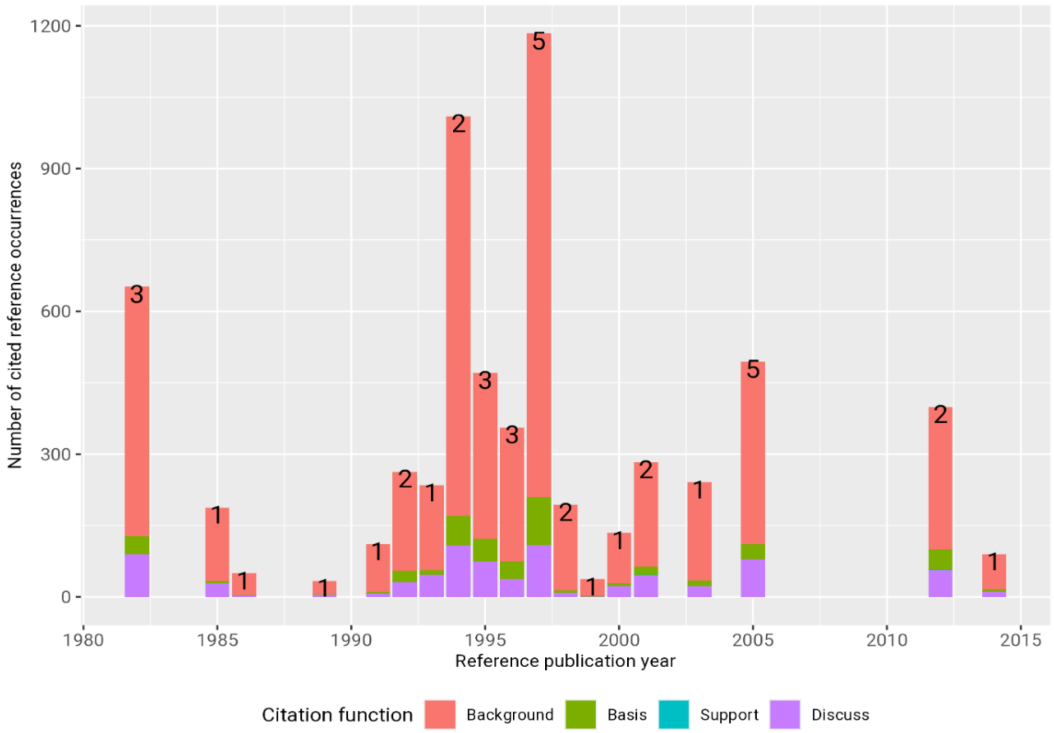

Figure 2. Annual numbers of citation functions associated with the citation instances for the 38 cited seminal papers of Q COMP. The number mentioned in each bar is the number of cited seminal papers in the respective RPY.

The RPYS method has been developed for the identification of seminal papers that are important in a certain research field. The method enables the user to identify significant peak years in the spectrogram and leads the user to those CRs that are mainly responsible for these peaks. Additional seminal papers can be detected by being long-term top-cited or even due to their outstanding absolute numbers of citations.

The results in Figure 1 and Figure 2 further specify RPYS results: The user can analyze in which sections of the citing papers and with which functions the seminal papers have been cited in certain years. If, for example, the user is interested in discussions of the cited seminal papers, the results in Figure 2 reveal that these discussions refer mainly to the cited seminal papers published around 1995. This result is confirmed by the results in Figure 1: Many seminal papers from around 1995 are cited in the Discussion section.

To exemplify the usefulness of the additional information from the CCI in this study, we tried to identify those seminal papers that have been cited due to the *methods* they offer in the realm of Q COMP. We expected that this analysis supplements the insights offered in the discussion of the cited seminal papers in Scheidsteger, et al. (2022). Figure 3 shows the numbers of citation instances associated with the section Methods and the function Basis across the RPYs of the cited seminal papers. The

Methods numbers are multiplied by three in order to facilitate comparison with the function Basis in the same plot.

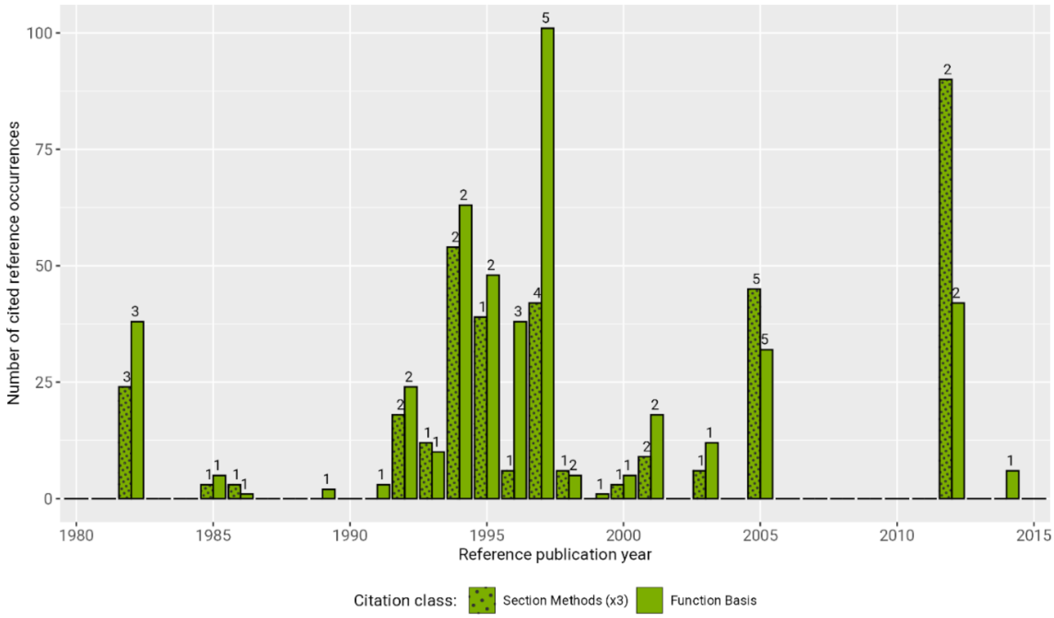

Figure 3. Annual numbers of the normalized section Methods (on the left, with dotted pattern) and the citation function Basis (on the right) associated with the citation instances for the 38 cited seminal papers of Q COMP. For better comparison, the numbers for the section Methods were multiplied by three. The number mentioned above each bar is the number of cited seminal papers in the respective RPY.

In Figure 3, we consider those RPYs with the seminal papers having the most citation instances associated with the section Methods and/or function Basis applying respective thresholds of five and 20, i.e., similar fractions of the respective maximal values. Four of these RPYs are identical with peak years of the Q COMP spectrogram in Scheidsteger, et al. (2022).

The most recent and highest Methods bar in Figure 3 is located in **2012**. Of the two cited seminal papers in this year, Fowler, Mariantoni, Martinis, and Cleland (2012) is associated with 29 of the 30 Methods citation instances. This result is confirmed by 39 of the 40 associated citation instances for the citation function Basis. Fowler, et al. (2012) provides an introduction to surface code quantum computing as one approach to construct fault-tolerant logical qubits from physical qubits. The authors of the paper intended to pave the road “towards practical large-scale quantum computation” as the title indicates. The paper is a prime example of an important methods contribution to the field.

In the next most recent year with high bars, **2005**, of 15 citation instances from five cited seminal papers, nine Methods occurrences (Basis occurrences: 16 of 32 instances) are associated with Aspuru-Guzik, Dutoi, Love, and Head-Gordon (2005). The paper presents “an efficient quantum algorithm for quantum chemical simulations of molecular energies—very much in the spirit of Feynman’s original ideas from more than 20 years before" (Scheidsteger, et al., 2022, p. 287). The authors refer to Feynman (1982) with five of the eight instances (Basis: 31 of 38 instances) in the oldest year with high bars in Figure 3, namely **1982**. Although the close connection of Feynman (1982) and Aspuru-Guzik, et al. (2005) has been identified by Scheidsteger, et al. (2022), it is confirmed by the additional analysis of section and function instances in this study.

In the year **2005**, another seminal paper contributes two of 15 instances to the Methods bar and seven of 32 instances to the Basis bar: Bravyi and Kitaev (2005) were able to significantly enlarge the error threshold in fault-tolerant quantum error-correcting schemes thus widening the operation window for quantum computing.

The year **1997** includes 14 citations to five cited seminal papers in the section Methods. The main contribution with nine citation instances stems from Shor's conference paper (Shor, 1997) assuring the quality and efficiency of the quantum algorithms he had introduced in Shor (1994). The result is confirmed by the citation function analysis: Shor (1997) accounts for 61 of 101 citation instances in this year with the highest bar for the function Basis.

The next largest contribution in **1997** (Methods: three of 14 instances; Basis: 13 of 101 instances) comes from a "Theory of quantum error-correcting codes" by Knill and Laflamme (1997). The paper plays a central role in the realization of quantum computing by stabilizing coherent states against the detrimental effect of physical noise.

A third cited seminal paper in **1997** contributes only one instance to the Methods bar, but 22 of 101 instances to the Basis bar. One reason for the few Methods occurrences is probably the fact that 17 of its Basis instances were found in papers not structured according to IMRaD, in particular not having a section Methods. Grover (1997) presents a quantum version of an unstructured search as the second practical quantum algorithm from the mid-1990s. While the algorithm "did not provide as spectacular a speed-up as Shor's algorithms, the widespread applicability of search-based methodologies has excited considerable interest in Grover's algorithm" (Nielsen & Chuang, 2010, p. 7).

Looking at cited seminal papers that are not associated with peak years in Scheidsteger, et al. (2022), we focused on the years 1992 and 1994 to 1996. The second highest Methods bar in Figure 3 refers to **1994** with a total of 18 Methods citation instances (from two cited seminal papers), 13 of which stem from Shor (1994). The author presents the first examples of quantum algorithms with a high practical value for the field—providing a first example of quantum cryptanalysis. The methodological importance of Shor (1994) is confirmed by the citation function analysis: 54 of 63 citation instances that belong to the citation function Basis go back to Shor (1994).

In **1995**, all 13 Methods instances and 47 of 48 Basis instances in Figure 3 are associated with Barenco et al. (1995). This paper provides universality proofs for certain quantum gates foundational for the construction of universal quantum circuits (Nielsen & Chuang, 2010).

The year **1996** shows a low bar with respect to the section Methods, but a high bar for the function Basis. This discrepancy can probably be explained by missing

Methods sections in citing papers (see above). Three seminal papers are contributing nearly equally to the citation instances. Steane (1996) with 13 function Basis citations used linear techniques from the classical theory of error-correcting codes to propose "Error correcting codes in quantum theory". These codes were subsequently generalized by Calderbank and Shor (1996) thereby proving that "Good quantum error-correcting codes exist". This paper gathered 15 function Basis citation instances. Despite the lack of CCI for older citing papers in WoS (see Table 3), we found that both seminal papers were cited within a section on the mathematical formalism, i.e., with explicit methodological focus, in Knill and Laflamme (1997), a seminal paper discussed above. Citations of the third seminal paper in 1996 by Bennett, DiVincenzo, Smolin, and Wootters (1996) were assigned ten times to the function Basis, and were located two times in the section Methods. In a section on the "recurrence method", this paper cites the other two seminal papers and even a preprint version of Knill and Laflamme (1997). The temporally close citation relations among these four seminal papers may point to a hot phase of methodological developments in Q COMP in the mid-1990s.

The high bar in **1992** with six citation instances from two publications is mainly (Methods: five of six instances; Basis: 23 of 24 instances) due to Deutsch and Jozsa (1992) proposing a second quantum algorithm that is proven to be faster than its classical counterpart. The latter was a classical deterministic algorithm that in the worst case would take exponentially more steps to decide the given logical problem.

Discussion

Since the introduction of RPYS, the method has been established in (professional) bibliometrics for identifying seminal papers in the history of a certain field. In this study, we investigated a possible extension of classical RPYS: the analysis of citation instances for cited publications with respect to normalized sections and citation functions in citing publications. We demonstrated the extension by using a sample dataset from the study of Scheidsteger, et al. (2022). The authors performed a classical RPYS using a publication set in quantum technology. For this case study, we focused on the subfield quantum computing (Q COMP). In order to answer RQ1, we analyzed (1) citation instances of a large set of cited papers in the subfield and, in more detail, (2) citation instances of cited seminal papers from the subfield. In both cases, citations in the Introduction section and citations classified as Background have by far the most frequent occurrences, but the citation instances of cited seminal papers show an about six percentage points higher prevalence than the citation instances of all cited papers from the subfield.

In order to answer RQ2, we exemplarily analyzed citation instances in the section Methods (2% of all CCI occurrences) and citations classified as having the function Basis (7%) for the set of cited seminal papers. For this set, we analyzed years with a lot of occurrences with respect to section Methods and/or function Basis. The analysis led to the identification of 13 cited seminal papers that can be labeled as especially important. These papers provide the methodological basis for many subsequent works in the field of Q COMP. They include, among others, the first proposals of quantum algorithms, pioneering works on quantum error correction, and the physical implementation of fault-tolerant logical qubits. The methodological focus of these 13 seminal papers had only rudimentarily been touched in Scheidsteger, et al. (2022). Their discussion of the reasons for the importance of those seminal papers would have benefited from the inclusion of the results presented in this case study. So it seems that CCI provided by Clarivate is useful to enrich and detail results from RPYS.

What are the limitations of the analyses in this study? (1) CCI is missing for many (older) publications in the WoS. This is a main disadvantage for the application of RPYS—a method which has been especially developed for historically oriented analyses. We expect, however, that the data situation will improve constantly, since the classification of citation instances is an ongoing process at Clarivate. (2) The IMRaD section scheme is not universally applied in science; especially not in those fields that are relevant for the present study like engineering, mathematics, and computer science (Moskovitz, Harmon, & Saha, 2024). We assume thus that there are misclassifications of normalized sections in the WoS data. A closer look at the CCI in our publication sets reveals that (i) many citing papers—especially those from computer science—lack a dedicated section Methods. (ii) Several citation instances are incorrectly assigned to the section Introduction, although they can be found at a later place in the publication (manuscripts usually start with the Introduction) and point to a foundational method. (3) In this study, we focus on the normalized section title and the citation functions to enrich RPYS in a first attempt, although additional CCI is available and other CCI has been proposed in the literature. We recommend that future studies include other CCI than we did (e.g., number of papers cited to support a particular statement) and try their usefulness for the enrichment of RPYS. We would like to encourage the use of our proposed RPYS enhancement in other research fields than Q COMP. We recommend to consider especially those fields with a recent rapid growth of publications (e.g., the research field on artificial intelligence). Then, a large share of publications with CCI can be expected.

Acknowledgments

Access to WoS bibliometric data has been supported via the German Kompetenznetzwerk Bibliometrie (Competence Network for Bibliometrics, http://www.bibliometrie.info), funded by the Federal Ministry of Education and Research (grant number: 16WIK2101A). We would like to thank Clarivate for detailed descriptions of the citation context information.

References

Aspuru-Guzik, A., Dutoi, A. D., Love, P. J., & Head-Gordon, M. (2005). Simulated quantum computation of molecular energies. *Science, 309*(5741), 1704-1707. doi: 10.1126/science.1113479.

Ballandonne, M., & Cersosimo, I. (2021). A note on reference publication year spectroscopy with incomplete information. *Scientometrics*. doi: 10.1007/s11192-021-03976-1.

Barenco, A., Bennett, C. H., Cleve, R., DiVincenzo, D. P., Margolus, N., Shor, P., . . . Weinfurter, H. (1995). Elementary gates for quantum computation. *Physical Review A, 52*(5), 3457-3467. doi: 10.1103/PhysRevA.52.3457.

Bennett, C. H., DiVincenzo, D. P., Smolin, J. A., & Wootters, W. K. (1996). Mixed-state entanglement and quantum error correction. *Physical Review A, 54*(5), 3824-3851. doi: 10.1103/PhysRevA.54.3824.

Bornmann, L., & Daniel, H.-D. (2008). What do citation counts measure? A review of studies on citing behavior. *Journal of Documentation, 64*(1), 45-80. doi: 10.1108/00220410810844150.

Bornmann, L., Haunschild, R., & Marx, W. (2023). Revolutions in science: The proposal of an approach for the identification of most important researchers, institutions and countries based on co-citation reference publication year spectroscopy exemplified at research on physical modelling of Earth's climate. *Journal of Information Science*, 01655515231161134. doi: 10.1177/01655515231161134.

Bornmann, L., & Marx, W. (2013). The proposal of a broadening of perspective in evaluative bibliometrics by complementing the times cited with a cited reference analysis. *Journal of Informetrics, 7*(1), 84-88. doi: 10.1016/j.joi.2012.09.003.

Bravyi, S., & Kitaev, A. (2005). Universal quantum computation with ideal Clifford gates and noisy ancillas. *Physical Review A, 71*(2), 022316. doi: 10.1103/PhysRevA.71.022316.

Calderbank, A. R., & Shor, P. W. (1996). Good quantum error-correcting codes exist. *Physical Review A, 54*(2), 1098-1105. doi: 10.1103/PhysRevA.54.1098.

Clarivate. (2022). Citation context in Web of Science. Retrieved January 30, 2025 from https://clarivate.com/webofsciencegroup/wp-content/uploads/sites/2/dlm_uploads/2022/05/202205-WoS-citation-context-final.pdf

Clarivate. (2024). Enriched cited references - citation function class. Retrieved January 30, 2025 from https://webofscience.zendesk.com/hc/en-us/articles/27713957430033-Enriched-Cited-References-Citation-Function-Class

Deutsch, D., & Jozsa, R. (1992). Rapid solution of problems by quantum computation. *Proceedings of the Royal Society of London. Series A: Mathematical and Physical Sciences, 439*(1907), 553-558. doi: 10.1098/rspa.1992.0167.

Feynman, R. P. (1982). Simulating physics with computers. *International Journal of Theoretical Physics, 21*(6), 467-488. doi: 10.1007/BF02650179.

Fowler, A. G., Mariantoni, M., Martinis, J. M., & Cleland, A. N. (2012). Surface codes: Towards practical large-scale quantum computation. *Physical Review A, 86*(3), 032324. doi: 10.1103/PhysRevA.86.032324.

Grover, L. K. (1997). Quantum mechanics helps in searching for a needle in a haystack. *Physical Review Letters, 79*(2), 325-328. doi: 10.1103/PhysRevLett.79.325.

Knill, E., & Laflamme, R. (1997). Theory of quantum error-correcting codes. *Physical Review A, 55*(2), 900-911. doi: 10.1103/PhysRevA.55.900.

Marx, W. (2021). History of RPYS. *figshare. Conference contribution.* doi: 10.6084/m9.figshare.14910615.v1.

Moskovitz, C., Harmon, B., & Saha, S. (2024). The structure of scientific writing: An empirical analysis of recent research articles in STEM. *Journal of Technical Writing and Communication, 54*(3), 265-281.
doi: 10.1177/00472816231171851.

Nielsen, M. A., & Chuang, I. L. (2010). *Quantum computation and quantum information* (10th anniversary edition ed.). Cambridge: Cambridge University Press.

Scheidsteger, T., Haunschild, R., Bornmann, L., & Ettl, C. (2021). Bibliometric analysis in the field of quantum technology. *Quantum Reports, 3*(3), 549-575. doi: 10.3390/quantum3030036.

Scheidsteger, T., Haunschild, R., & Ettl, C. (2022). Historical roots and seminal papers of Quantum Technology 2.0. *NanoEthics*. doi: 10.1007/s11569-022-00424-z.

Schmidt, M., Rimmert, C., Stephen, D., Lenke, C., Donner, P., Gärtner, S., . . . Stahlschmidt, S. (2024). The data infrastructure of the German Kompetenznetzwerk Bibliometrie: An enabling intermediary between raw data and analysis. doi: 10.5281/zenodo.13935407.

Shor, P. W. (1994). *Algorithms for quantum computation: Discrete logarithms and factoring*. Paper presented at the 35th Annual Symposium on Foundations of Computer Science.

Shor, P. W. (1997). Polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer. *SIAM Journal on Computing, 26*(5), 1484. doi: 10.1137/S0097539795293172.

Sollaci, L. B., & Pereira, M. G. (2004). The introduction, methods, results, and discussion (IMRAD) structure: a fifty-year survey. *Journal of the Medical Library Association, 92*(3), 364-371.

Steane, A. M. (1996). Error Correcting Codes in Quantum Theory. *Physical Review Letters, 77*(5), 793-797. doi: 10.1103/PhysRevLett.77.793.

Tahamtan, I., & Bornmann, L. (2019). What do citation counts measure? An updated review of studies on citations in scientific documents published between 2006 and 2018. *Scientometrics, 121*(3), 1635–1684. doi: 10.1007/s11192-019-03243-4.

Thor, A., Bornmann, L., & Haunschild, R. (2018). CitedReferencesExplorer (CRExplorer) manual. Retrieved December 19, 2019, from https://andreas-thor.github.io/cre/manual.pdf

Thor, A., Marx, W., Leydesdorff, L., & Bornmann, L. (2016). Introducing CitedReferencesExplorer (CRExplorer): A program for reference publication year spectroscopy with cited references standardization. *Journal of Informetrics, 10*(2), 503-515. doi: 10.1016/j.joi.2016.02.005.