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Sources of Google Scholar citations outside the Science Citation Index: A comparison between four science disciplines

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For practical reasons, bibliographic databases can only contain a subset of the scientific literature. The ISI citation databases are designed to cover the highest impact scientific research journals as well as a few other sources chosen by the Institute for Scientific Information (ISI). Google Scholar also contains citation information, but includes a less quality controlled collection of publications from different types of web documents. We define *Google Scholar unique citations* as those retrieved by Google Scholar which are not in the ISI database. We took a sample of 882 articles from 39 open access ISI-indexed journals in 2001 from biology, chemistry, physics and computing and classified the type, language, publication year and accessibility of the Google Scholar unique citing sources. The majority of Google Scholar unique citations (70%) were from full-text sources and there were large disciplinary differences between types of citing documents, suggesting that a wide range of non-ISI citing sources, especially from non-journal documents, are accessible by Google Scholar. This might be considered to be an advantage of Google Scholar, since it could be useful for citation tracking in a wider range of open access scholarly documents and to give a broader type of citation impact. An important corollary from our study is that Google Scholar's wider coverage of Open Access (OA) web documents is likely to give a boost to the impact of OA research and the OA movement.

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Introduction

Although the Internet is already a significant source of information for individuals and organizations, the ever increasing volume of online literature has been a cause of anxiety for librarians and information science professionals trying to deal with the information overload (e.g., [BAWDEN & AL., 1999]). On one hand an increasing number of authors, journals and institutions are willing to publish their research results online [SWAN & BROWN, 2004; 2005] and on the other hand locating partly organized documents through commercial search engines with different retrieval biases [MOWSHOWITZ & KAWAGUCHI, 2005] which do not use classic indexing practices [LANCASTER, 2003], seems to be one of the main challenges of web information retrieval. Hence, there has been interest in extracting citation information for the more effective retrieval of scholarly web documents. In fact, the hope that "a universal Internet-based bibliographic and citation database linking every scholarly work" [CAMERON, 1997] as well as the development of web-based citation databases, such as *CiteSeer*, *Citebase* and *Google Scholar* with a huge amount of citation information from web documents, springs from Eugene Garfield's pioneering view of citation indexing as an alternative to the subject or keyword indexing of scholarly works [GARFIELD, 1955].

While proposing a model of fully automatic document retrieval using bibliographic information is not new [SALTON, 1963; 1971], its effectiveness compared to human-like indexing has been debated (e.g., [GARFIELD, 1965; LANCASTER & WARNER, 2001]). However, today there are web-based citation databases with content quality different from the Institute for Scientific Information (ISI) databases which cover the "world's most important and influential refereed journals" through an "extensive evaluation process" [ISI JOURNAL SELECTION PROCESS, 2006]. While there might be little controversy about the value of using automatic citation extraction techniques for scientific documents such as patents [LAWSON & AL., 1996], the situation is different for the web. Any web documents (peer reviewed or non-peer reviewed) can be processed using heuristics to extract source information and references based upon the known structures of scientific full-text papers [BOLLACKER & AL., 1988; LAWRENCE & AL., 1999; GOOGLE SCHOLAR, 2006] to build an index with cited and citing associations.

Many have discussed issues concerning the selective coverage of the scientific literature, the over-representation of English language journals (e.g., [MACROBERTS & MACROBERTS, 1996; 1989]) and disciplinary differences in the overall coverage of ISI databases, especially in social science and the humanities [MOED, 2005]. Others use this as evidence of the advantages that automatic web-based citation indexes may provide less biased citation searching in broader disciplines and types of documents, especially those not covered by the ISI [LAWRENCE & AL., 1999; HITCHCOCK & AL., 2002]. Since "the vast majority of authors" would willing to deposit copies of their articles in an institutional or subject-based repository [SWAN & BROWN, 2005] and over 90% of journals "have given their official green light to author self-archiving" [HARNAD & AL., 2004], an increasingly amount of citation information from web documents (OA or non-OA) seems to be available and it is reasonable to use automated citation extraction techniques for locating relevant web documents. Perhaps this evolution of the platforms for publishing the scientific literature was the incentive for the ISI to develop *The Web Citation Index*, "a multidisciplinary citation index of web-accessible, scholarly research papers" using both automatic citation indexing techniques and human content selection [MARTELLO, 2006].

If there is a switch to using non-ISI web citations (described below) then we need evidence of their intellectual impact in scholarly communication. In this paper we investigate the non-ISI citations to open access (OA) journal articles. Google Scholar (http://scholar.google.com) is the largest new multi-disciplinary tool that can be used for accessing and measuring 'hidden' citations, especially from non-journal web documents which are not traced by conventional bibliographic and citation databases. Google Scholar contains citation information from many publishers, but does not apply any quality control procedure for its collection of journal publications and includes substantial coverage of non-journal documents, such as conference papers, theses, books, research/technical reports, and preprint repositories [GOOGLE SCHOLAR, 2006]. For this reason, it seems that a significant number of non-ISI citations from open access and non-open access documents in different subject areas, especially those from non-journal sources, could be retrieved through Google Scholar. Some of these documents might never have been indexed by commercial search engines, so they would be 'invisible' to web searchers, and some would be similarly invisible to the ISI and other specific web-based citation service users.

Previous research has suggested that 72% of authors were using Google to search the web for scholarly articles [SWAN & BROWN, 2005] and hence it can be expected that a considerable number of researchers and students would be willing to try Google Scholar. A question that follows is whether researchers and students, especially those who have no access to fee-based citation indexes (i.e., the Web of Science and Scopus) can use Google Scholar for citation tracking of scholarly information? As the part of this important question there are many subsidiary issues. What are the characteristics of sources of Google Scholar citations which do not overlap with ISI citations such as type, language, publication year and accessibility? Are disciplinary differences a significant factor in receiving Google Scholar unique citations to journal articles? No previous study has investigated the characteristics of sources of Google Scholar unique citations, although some have compared ISI and Google Scholar citation impact (e.g., [BAUER & BAKKALBASI, 2005; BELEW, 2005; JACSO, 2005B; PAULY & STERGIOU, 2005; KOUSHA & THELWALL, TO APPEAR]).

This is a follow up study based upon our previous investigations of 108 Open Access (OA) journals in eight science and social science disciplines which found significant correlation between ISI citations and Google Scholar citations [KOUSHA & THELWALL, TO APPEAR]. As with citation analysis, since a direct interpretation of this relationship between online and offline variables is important [OPPENHEIM, 2000; THELWALL, 2006], we also counted overlaps between ISI and Google Scholar citations to the sampled articles in four science disciplines and found that the overall relative overlap percentage for the ISI was 57% and for Google Scholar was 43% [KOUSHA & THELWALL, TO APPEAR]. Hence, just under half of Google Scholar citations were in the ISI index, and Google Scholar covered just over half of the ISI's sources (publications).

For the purpose of this study we define Google Scholar unique citations to be the citations to our sampled articles retrieved by Google Scholar which were not in the ISI database. In this research we focus on the characteristics of these 'unique' citing sources from Google Scholar, using four (*hard*) science areas. We explore the type, language, publication year and accessibility of the sources of Google Scholar unique citations to articles in 39 ISI-indexed OA journals in biology, chemistry, physics and computing. The purposes are to identify the *causes* of differences between conventional and web-extracted citation patterns and to shed light on the role of non-journal documents such as conference papers, e-prints, research reports and dissertations in formal scholarly communication in the studied disciplines.

Related studies

ISI Citation Impact

In 1989, the first open access fully peer-reviewed electronic journal, *Psycoloquy*, was published [HARNAD, 1991] and by 2004 about 5% of peer-reviewed research journals worldwide were open access [HARNAD & AL., 2004]. Out of more than 2200 full text and quality controlled open access journals worldwide [DOAJ, 2006] at least 10% have been indexed by ISI databases [ISI PRESS RELEASE, 2004], indicating their scholarly impact in research communities. There is also evidence that OA journals and non-OA journals can have similar citation impacts [ISI PRESS RELEASE, 2004] and that free online accessibility of papers increases citation impact in computer science [LAWRENCE, 2001], astrophysics [KURTZ, 2004; SCHWARZ & KENNICUTT, 2004], mathematics [DAVIS & FROMERTH, 2006], psychology [SHIN, 2003] as well as in a wider cross-disciplinary context (e.g., [ANTELMAN, 2004; BRODY & AL., 2004; HAJJEM & AL., 2005; HARNAD & BRODY, 2004]). Although the purpose of most of the above citation analysis studies was measuring the impact of online journals, the citation data came from the exclusive set of journals indexed by the ISI.

Link, web and URL Citations

Since a significant number of OA journals are not indexed by the ISI, researchers have used alternative methods to compare conventional and web-based citation impact (see [THELWALL & AL., 2005]). The first researcher, SMITH [1999], used web citation analysis techniques for 22 Australasian e-journals, finding no significant relationship between inlinks and ISI Impact Factors. HARTER & FORD [2000] also studied links and ISI citations to 39 scholarly e-journals, finding no significant correlation. In contrast, VAUGHAN & HYSEN [2002] found a significant correlation between the number of external links and the journal impact factor for ISI-indexed library and information science journals. In some follow-up research VAUGHAN & THELWALL [2003] found that journals in the field of law and library and information science which had more online content received more links.

In contrast to above quantitative methods (mainly correlation tests), KIM [2000] and HERRING [2002] applied qualitative methods to explore motivations for hyperlinking in scholarly electronic articles, finding that researchers used hyperlinks for both scholarly and non-scholarly reasons. WOUTERS & VRIES [2004] also studied hyperlinking references in five disciplines, finding that the majority pointed to the conventional scholarly literature.

While most early investigations compared web links with ISI citation counts or journal Impact Factors, VAUGHAN & SHAW [2003] used web citations (e.g., mentions of article titles in web pages), finding significant correlations between ISI citations and citations in the web to journal articles in library and information science. Based upon a classification of web citations they suggested that web and ISI citation counts measure a similar level of impact. Covering four areas of science they also found similar relationship between ISI and web citations to journal articles in four science subject areas [VAUGHAN & SHAW, 2005]. They classified web citations to examine the intellectual impact of the articles, concluding that web citation counts might potentially supplement or replace ISI citation counts as an impact measure and could provide an increased diversity in coverage.

KOUSHA & THELWALL [2006] extracted URL citations (mentions of an URL in the text of a web page) to open access peer-viewed articles in library and information science to compare traditional and web-based citation patterns. They found a significant correlation between ISI and URL citation counts. A classification of URL citations showed that 43% were created for formal scholarly reasons equivalent to citation and the overall results were mainly influenced by text URL citations from non-HTML documents.

Based upon previous methods, KOUSHA & THELWALL [TO APPEAR] combined web and URL citation methods to collect more comprehensive citation data from web documents (e.g., hyperlinked or non-hyperlinked article titles or URLs). They found significant correlations between ISI citations and Google Web/URL citations in four science and four social science disciplines; with similar results when comparing within and across (most) journals, supporting previous findings that web-extracted citation patterns are likely to be similar to conventional citations patterns and can potentially be used for impact assessment.

Autonomous citation indexing

Although recent studies have found evidence that there is some commonality between traditional and web-extracted citations from commercial search engines, there are relatively few studies across several subject areas comparing conventional citations (e.g. ISI citations) with citations from web-based citation indexes. GOODRUM, & AL. [2001], for instance, compared ISI and CiteSeer citations from online computer science papers. They found more citations from conference papers than ISI articles, indicating the importance of conference papers among computer professional for disseminating research results. ZHAO & LOGAN [2002] compared online and offline citation patterns for the XML research area, finding more citations from CiteSeer than the ISI counterpart. ZHAO [2005] found a 10% overlap between citing papers by CiteSeer and the ISI in the XML research field, indicating that XML articles published in journals were not mainly open access and papers published on the web were not well represented in journals indexed by the ISI.

While the above results were based upon CiteSeer as a specific web-extracted citation database in computing, other researchers have extracted log files from preprint archives to discover the relationship between citations to articles and researchers' usage patterns such as time between depositing and receiving citation [HARNAD & CARR, 2000; KURTZ & AL., 2005].

With advent of Google Scholar several reviews and papers have discussed its problems and citation tracking capabilities (e.g., [FRIEND, 2006; JACSO, 2004; 2005A; 2005B; NOTESS, 2005]), but the few articles that have compared Google Scholar with ISI citation data are exploratory and small-scale in nature. BAUER & BAKKALBASI [2005], for instance, compared the citation counts from the ISI Web of Science, Elsevier's Scopus, and Google Scholar to articles published in 1985 and 2000 in just the *Journal of the American Society for Information Science and Technology* (JASIST), finding significantly higher citation counts from Google Scholar than either the Web of Science or Scopus for the year 2000. PAULY & STERGIOU [2005] also compared citations from the ISI and Google Scholar to 99 papers in 11 disciplines as well as 15 highly-cited articles, finding nearly equal patterns for articles published after 1990. BELEW [2005] selected six academics at random and compared citations to publications by these authors indexed by the ISI with those reported by Google Scholar, finding a small overlap between two databases.

KOUSHA & THELWALL [TO APPEAR] examined correlations between ISI and Google Scholar citations to a sample of 1,650 articles from 108 Open Access journals published in 2001 in four science and four social science disciplines, finding results in all cases. There were large disciplinary differences in the studied areas, suggesting that Google Scholar gives more comprehensive results in the social sciences, but not in science (excluding computing). They also examined the overlap between ISI citations and Google Scholar citations in four science disciplines, finding that the overall relative overlap percentage for the ISI (overlapping ISI citations with Google Scholar citations divided by total ISI citations) was 57%. They also found that the percentage for ISI citations was about 12% and for Google Scholar 22% within a four-month period.

Research questions

Despite all the above investigations, it seems that no previously study has explored the *characteristics* of sources of Google Scholar unique citations which don't overlap with ISI citations through a large systematic sample in different science disciplines. On the basis of the above findings there have been claims that the web could be an alternative to the ISI for citation impact calculations. However, there are differences in the extent to which disciplines publish on the web and write journal articles [KLING & MCKIM, 1999; FRY & TALJA, 2004] and so more information is needed about disciplinary differences in online citation counts and types of non-ISI citing sources. This may also shed light on the strengths and weaknesses of the ISI's coverage of the scholarly literature.

Three questions were chosen to explore characteristics of sources of Google Scholar unique citations (those not overlapping with ISI citations) to articles in 39 Open Access (OA) ISI-indexed journals in 2001 from biology, physics, chemistry and computing and apparent disciplinary differences in terms of receiving unique web-extracted citations.

- What is the document type distribution of Google Scholar citing sources (i.e., journals articles; conference/workshops papers; research/technical reports; thesis/ dissertations; books/book chapters; e-print archives and preprints)?
- What language (English/other languages), publication year (2001–2006), and content level (open access/non-open access) do Google Scholar unique citations have?
- Are disciplinary differences an important factor in the above types and characteristics of Google Scholar unique citations?

Method of study

Journal and article selection

Since this study is a follow up qualitative investigation, its method is based upon our previous research which examined the overlap between ISI citations and Google Scholar citations in four scientific disciplines [KOUSHA & THELWALL, TO APPEAR]. We used the same dataset to explore characteristics of the identified Google Scholar unique web citations. Hence, we again defined OA journals as ISI-indexed English language journals freely accessible on the web (in electronic only or both in electronic and print formats) and chose biology, physics, chemistry, and computing to represent a range of (hard) sciences. We used OA articles published in 2001 in order to allow time to receive citations.

For each selected journal, a sample was used to give a systematic selection of journal articles (omitting reports, editorials, and book reviews). In each discipline journals with more published articles had more articles in our final sample. This method of article selection allowed us to take a random sample in each discipline proportional to the total number of articles in each journal. Table 1 summarises the data used in this study. Ultimately, our sample included 882 research articles from 39 open access ISI-indexed journals in 2001 from biology, physics, chemistry and computing). Appendix shows the selected journals.

Table 1. Number of unique citations in Google Scholar and ISI

Disciplines	Journals	Articles sampled	ISI citations	Google Scholar citations	ISI citations overlapping with Google Scholar	Google Scholar unique citations	ISI unique citations
Biology	14	262	1288	1113	847	266	441
Chemistry	10	276	668	279	218	61	450
Physics	11	262	1111	1313	690	623	421
Computer	4	82	1117	2884	632	2252	485
Total	39	882	4184	5589	2387	3202	1797

ISI and Google Scholar citations

For ISI citations we recorded the number of citations to each article by selecting the “times cited” option in the ISI Web of Science. For Google Scholar citations, we entered the titles (taken from journal web site tables of contents) of all 882 sampled articles as phrase searches in the main Google Scholar search page. It was necessary to omit a mathematical portion of some article titles (especially in physics, chemistry and biology) during the search process. In fact, we sometimes conducted several searches for the same journal articles in order to generate effective results. We then recorded the number of Google Scholar citing sources, if displayed, by clicking the “cited by” option below each retrieved record.

Sometimes we found duplicate records (i.e., journal, conference, e-print papers) from the same journal articles and author(s) in our Google Scholar searches with a different number of citing sources. For this reason, we manually checked the search results against the original citation information to avoid false matches and also removed any duplicated citing documents to our sampled articles from different sources, although it was time consuming task. This shows that Google Scholar has major searching limitations and researchers should cautiously use it and check the retrieved results for bibliometrics/scientometrics analysis. Note that all the ISI and Google Scholar searches in this study were conducted for each discipline and article respectively during January 2006 in order to minimize the potential impact of time on increasing the citation counts in both databases.

Google Scholar unique citations

As shown in Table 1, our previous study showed that out of 4,184 ISI citations, 2,387 records were duplicated in the Google Scholar search results. There were 3,202 “*unique citations*” from Google Scholar which didn’t occur within the ISI citations for our study. We manually highlighted those unique citations from Google Scholar for the further qualitative study. We examined all Google Scholar unique citations in biology, chemistry and physics, but took a random sample of 1000 unique citations from computing to restrict the size of the study. As a result, we studied 1950 Google Scholar unique citations to present a detailed view of their characteristics in the four science disciplines. We categorized the unique citations based upon the faceted classification scheme below. This categorization was based upon our previous experience with library and information science OA journals [KOUSHA & THELWALL, 2006] and related research on journal web sites [VAUGHAN & SHAW, 2003; 2005]. However, in some cases we modified our predefined categories to cover new characteristics identified. The method that we used for data collection was very useful for separating out the characteristics of citing sources for type, publication year, and accessibility of sources of citations. Thus, we could reach different conclusions and analysis from the same dataset for different purposes.

During the matching process, we found that some citing sources posted to preprint archives especially *ArXive* (in physics, computer science and mathematics) and *Cogprints* (in cognitive sciences) were also indexed by the Institute for Scientific Information databases with similar titles, authors, abstracts and publication years. Perhaps the main reason for this similarity was that about 10 percent of ISI-indexed journal articles in physics published during 1992–2001 were first published as open access preprints in ArXive [HARNAD & BRODY, 2004]. Physics has a strong preprint sharing culture. Authors in the physics and computer science are willing to deposit preprints more frequently than postprints (peer-reviewed articles) to e-print archives [SWAN & BROWN, 2005]. We considered such citations as overlapping records in both databases after matching bibliographic information from both citing sources in order to avoid counting the overlapping documents with similar scholarly contents as Google Scholar unique citations. This gives more accurate results, although it is very time consuming to check. However, it is possible that some authors post a preprint paper (articles prior to peer review) to e-print archives and publish the same version (or with some minor changes) to ISI-indexed journals. We didn't compare the whole contents of preprints and ISI papers against each other for minor changes, however, to make the project manageable.

In many cases we could neither directly recognise type of publication from the Google Scholar main page results nor through the available full-text versions of citing documents. Thus, we checked the main (root) URL address of documents (or some part of URLs) to explore the types of citing sources. For instance, we found many Google Scholar citing sources deposited online which were from institutional self-archiving practices especially from authors' web CVs. We used the above method for exploring bibliographic information about citing sources.

Type of publication

Since it was important for us to discover the predominant types of sources of unique citations from Google Scholar, we manually checked and classified these sources into one of the following types of publication.

- Journal article
- Conference/workshop paper
- Research/technical report
- Thesis
- Book/book chapter
- E-print/preprint
- Other (or unidentified)

Language

To investigate the language of Google Scholar unique citations and the role of language diversity in scholarly communication, we classified citing documents into one of the following languages groups. The choice included English as the dominant language, Chinese as a common and fast-rising language, and other non-English languages.

- English
- Non-English with Roman scripts (e.g., French, Dutch, Spanish)
- Chinese

Publication year (2001–2006)

One key question in our research was how long it took for an OA article to be formally cited by web documents. Thus, we tried to identify the publication year of citing sources during 2001–2006 in different ways, such as referring to the header, footer or footnotes of documents, using Google Scholar search results, checking the main (root) URL address of documents, and searching for conference information on the web. However, we couldn't find the exact publication year of some citing documents and classified them as "not clear".

Content accessibility (open access / non-open access)

We classified citing sources into open access or non-open access. An open access document is one where the fill text is available to any web user without charge or any kind of registration process.

Findings

Disciplinary differences in citation types

Figure 1 shows that in the four studied disciplines the dominant types of Google Scholar unique citing sources to OA articles were journal papers (34.5%), conference/workshop papers (25.2%), and e-prints/preprints (22.8%) respectively. Figure 1 also shows that there were huge disciplinary differences between types of citing documents in the four disciplines. For instance, in biology and chemistry the majority of unique citations from Google Scholar were from journal papers with 181 (68%) and 54 (88.5%) citations respectively. Perhaps one reason for the relatively high percentage of journal citations (88.5%) in chemistry could be the classic dependency of authors on journal publications, compared to conference papers (0%) and preprints (0%). This supports previous findings in the same subject areas that the reception of e-prints in chemistry by authors is very poor [BROWN, 2003].

In contrast, in physics e-prints/preprints (47.7%) and in computer science conference/workshop papers (43.2%) are the most predominant type of sources of unique citations from Google Scholar. The results indicate that the type of unique citations from web documents vary significantly between hard science disciplines and support previous findings that conference papers in computer science were relatively more frequently cited online and much less by ISI articles [GOODRUM & AL., 2001]. In physics, the e-prints archive initiative (especially, http://arXiv.org) is often the first choice for authors to publish the results of current research, by depositing a preprint [HARNAD & CAR, 2000].

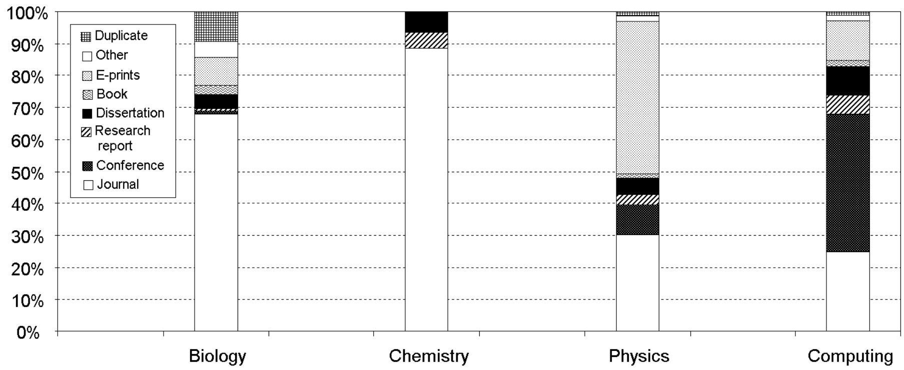

Figure 1. Classification of type of unique citing sources from Google Scholar in four science disciplines

It is interesting that the number of unique citations from theses were low and similar in the four studied disciplines, with an average percentage of 7.2%. However, OA ISI-indexed articles received more citations from online dissertations than online research/technical reports and books. It is also interesting that in biology and chemistry citations from online dissertations are more common than those from conference papers. It seems that increased hosting of online theses and dissertations by universities around the world may be the main reason for this result. We found 45 (2.3%) duplicated citations in the Google Scholar search results, most of which had cited the same OA articles but were extracted from two or more different publishers by Google Scholar.

Languages

Figure 2 shows that the common languages of sources of unique citations from Google Scholar differ by discipline. For instance, in biology and chemistry about 36% and 23% of unique citations were from Chinese language documents and 7% and 11.5% of citations were in other Roman script languages respectively. In contrast, in both physics and computer science about 96% of unique citations were from English language documents. We tried to find an explanation for the high percentage of Chinese language unique citations in biology and chemistry and found that nearly all citations retrieved in this study were from two Chinese language citation databases indexed by Google Scholar, including Wanfang Data (http://www.wanfangdata.com.cn) which is a task force of the Institute of Scientific & Technological Information of China (ISTIC), and VIP Information (http://engine.cqvip.com) which collects, processes and offers a huge quantity of periodical data in Chinese. An underlying cause may also be the strength of Chinese research in these areas [GLÄNZEL & SCHOEPFLIN, 1994]. We did not find citations from any other non-Roman languages. It seems that language diversity in sources of unique citations also depends on the languages of the databases that Google Scholar indexes. It is unclear, however, whether this is because Google Scholar has poor coverage of non-Roman language citation databases and online papers or because few such papers and databases exist.

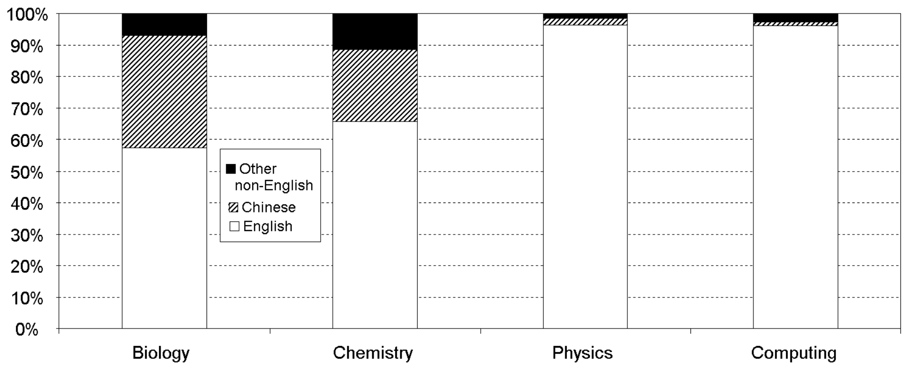

Figure 2. Languages of sources of unique citations from Google Scholar

Rapid citation impact

We found that about 31% of the sources of unique citations in the four studied disciplines were published during 2001–2002. In other words, it took about two years for OA articles in this study to receive "*rapid citations*" (the period of time that an OA article receives a formal citation from other web documents after about two years, 2001–2002, of publishing). As shown in Figure 3, OA articles in physics received a relatively higher percentage of citations (about 45%) during the same period of time. In fact, physics OA articles published in 2001 received about 24% of their citations within less than a year. It is known that the online availability of articles can increase their citation impact [LAWRENCE, 2001; SHIN, 2003; KURTZ; 2004] and that submitting an article to preprint archives lessen the average time between writing a paper and receiving a citation [BRODY & AL., 2002]. This latter point suggests a rapid research culture for physics which would explain our results. In order to support this assumption we compared the immediacy index score in the four studied disciplines based upon ISI *Journal Citation Reports* [2004], finding that physics has a similar mean and median to other three studied disciplines, and so it seems this is not the case. It is possible that the rapid citation for physics in our results are peculiar to OA articles, but we have no concrete evidence to support this.

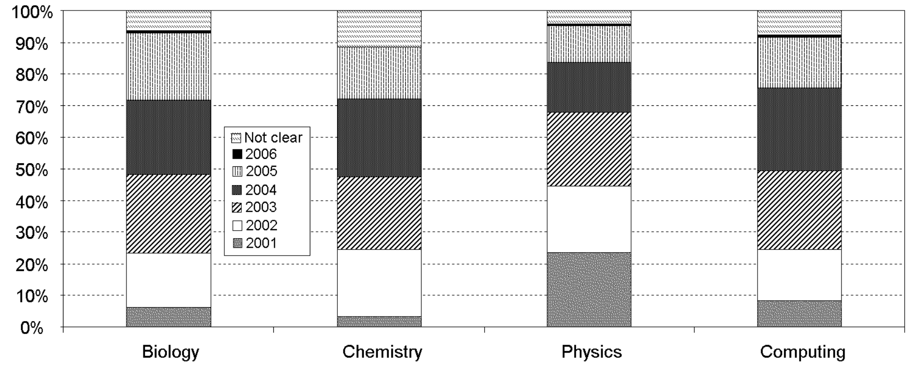

Figure 3. Publication year of sources of unique citations from Google Scholar

Accessibility of citing sources

As shown in Table 2, out of 1905 Google Scholar unique citations, 70% were freely accessible online. The result shows that the unique citing documents retrieved from Google Scholar were dominated by full text sources. Table 2 also shows results about the proportion of open access or non open access types of publication (e.g., OA/non-OA journal citations) journal articles. In biology and chemistry, for example, the majority of sources of unique citations from Google Scholar were from non-open access journals. It is interesting that after journal articles, citations from OA theses and dissertations were second in targeting OA articles in both disciplines. However, further research is needed to measure the impact of online dissertations in scholarly communication on the web in other different subject areas.

As shown in Table 2 in physics, out of 614 unique citations, 48% were from e-print and preprint archives. We found that 98% of these were from arXiv.org, indicating the dominant position of this e-prints archive. Non-OA journal articles also had a considerable citation impact in physics with 25% of citations to OA articles. In computer science, the largest type of unique citing sources was from freely accessible conference papers (34%). However we found 10 of citation from non-OA conference papers for instance from IEEE conference proceedings. OA and non-OA journal articles and e-print/preprints had nearly equal percentage of unique citations, ranging from about 12%–13%. It is noteworthy that sources of all unique citations from dissertations were freely accessible (full text) and only about 5% of citations from conference papers were non-OA.

Table 2. OA and non-OA sources of citations based upon the type of publication

	Open Access Citations							
Type / Discipline	Journal	Conf.	Res. Rep	Diss.	Book	E-print/ pre-print	Other	Total OA citation %
Biology	61 (25.3%)	2 (08%)	2 (08%)	12 (5%)	5 (2.1%)	23 (9.5%)	3 (1.2%)	108 (8.1%)
Chemistry	20 (32.8%)	0 (0%)	2 (3.3%)	4 (6.6%)	0 (0%)	0 (0%)	0 (0%)	26 (2%)
Physics	36 (5.9%)	53 (8.6%)	20 (3.3%)	32 (5.2%)	6 (1%)	297 (48.4%)	6 (1%)	450 (33.9%)
Computing	117 (11.8%)	333 (33.7%)	56 (5.7%)	89 (9%)	13 (1.3%)	124 (12.5%)	11 (1.1%)	743 (56%)
Total %	234 (12.3%)	388 (20.4%)	80 (4.2%)	137 (7.2%)	24 (1.3%)	444 (23.3%)	20 (1%)	1327 (100%)
Total % Accessibility	1327 (69.7%)							

	Non-Open Access Citations						
Type / Discipline	Journal	Conf.	Res. Rep	Book	Other	Total Non-OA citation %	Total %
Biology	120 (49.8%)	0 (0%)	0 (0%)	3 (1.2%)	10 (4.1%)	133 (23%)	241 (100%)
Chemistry	34 (55.7%)	0 (0%)	1 (1.6%)	0 (0%)	0 (0%)	35 (6.1%)	61 (100%)
Physics	152 (24.8%)	5 (0.8%)	0 (0%)	2 (0.3%)	5 (0.8%)	164 (28.4%)	614 (100%)
Computing	132 (13.3%)	99 (10%)	1 (0.1%)	7 (0.7%)	7 (0.7%)	246 (42.6%)	989 (100%)
Total %	438 (23%)	104 (5.5%)	2 (0.1%)	12 (0.6%)	22 (1.2%)	578 (100%)	1905 (100%)
Total % Accessibility	578 (30.3%)						1905 (100%)

Further analysis

ISI unique citations

As shown in Table 1, in chemistry we found a relatively small number Google Scholar unique citations (61) and much higher number of ISI unique citations (450). Thus, it was important to explore the characteristics of ISI unique citations and to examine missing ISI citations in Google Scholar database in this subject area. Once again we highlighted 450 ISI unique citations in our search results and recorded the journal names and publishers (through the Web of Science database) for each citation.

Figure 4 shows that 41% of ISI unique citations were from Elsevier, one of the major publishers of scientific journals with over 70 chemistry and chemical engineering titles. One explanation for such missing citations in Google Scholar is that it couldn't directly access the Elsevier publication database [JACSO, 2005A] in order to index the 'citing references' to Open Access chemical journal articles in this study. In other words, Google Scholar might have the facility to index 'abstract and bibliographic information' from the Elsevier publications through a third party, such as Ingenta, but it couldn't build an index of the cited and citing relationship which is necessary for citation indexing. However, those citing sources from Elsevier publications which were also open access (i.e., preprints/postprints archives) or indexed in digital libraries with citing reference information (i.e., The ACM Digital Library) could have appeared in Google Scholar searches.

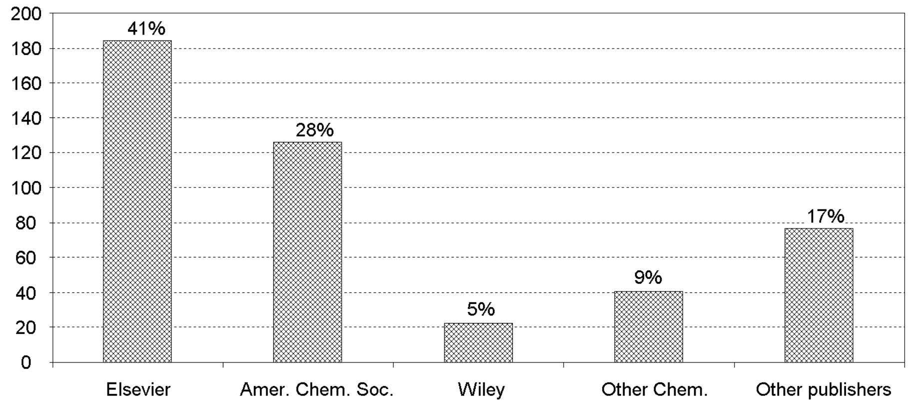

Figure 4. Distribution of ISI unique citations from publishers in chemistry

As shown in Figure 4, another major source of ISI unique citations were from the American Chemical Society (ACS) publications with several high impact scholarly journal titles. Although Google Scholar directly indexes bibliographic information and abstracts of journal articles from ACS publications, it couldn't access the references of those articles which targeted OA articles in this study. We found the same reason for missing ISI unique citations in our Google Scholar searches from Wiley InterScience and other individual publishers. This supports the claim that ISI has excellent coverage for research evaluation in chemistry [MOED, 2005] based upon the classic citation indexing practices. Moreover, the Google Scholar citation tracking capability is limited by its need to access references of web documents.

We also found that in chemistry many ISI unique citations were from high impact journals as reported by the ISI *Journal Citation Reports* (JCR). Most notably, we found that 10% of ISI unique citations were from *Analytical Chemistry* with the second highest Impact Factor score (in the analytical chemistry category) at the time of this study. This undermines the value of Google Scholar in chemistry, at least for citations.

We found 21 ISI unique citations from OA journal titles which had other articles that matched with Google Scholar citations. In other words, some citation information was missing from Google Scholar even for journals that it covered. For instance, we found 16 overlapping results between ISI and Google Scholar citations and 8 ISI unique citations from *Analytical Sciences* (an open access journal), supporting previous claims that Google Scholar has inconstancy in covering citation information from the same sources [JACSO, 2005B]. Since Elsevier is one of the main publishers in life sciences, it is likely that the major source of ISI unique citations in biology also come from this publisher.

Discussion

Disciplinary differences in types of google scholar citations

Although the most Google Scholar unique citations targeting OA articles in the four studied disciplines were from journal papers, conference papers, and e-prints/preprints, there were huge disciplinary differences indicating that variations among subject areas were important (discussed below). Finding a relatively high percentage of Chinese language unique citations in biology and chemistry (excluding physics and computing) from two Chinese databases and not locating any citations in non-Roman languages suggests that Google Scholar might be selective in indexing publishers' web sites, citation databases and digital archives, and any results can be inconsistent over the time. However, this might spring from a high research contribution in the Chinese language in the above disciplines. Finding a small but nearly similar proportion of Google Scholar unique citations from online theses in the four studied disciplines indicates the involvement of universities for publishing their thesis and dissertations in different subject areas.

Why are there huge disciplinary differences in the publication types of Google Scholar unique citations? One explanation is differing research culture of disciplines for using different mediums for dissemination of research results. For instance in both biology and chemistry it seems that authors have the classic dependency on journal publication. Perhaps that is the main reason why ISI has "excellent" coverage for research evaluation in the above disciplines [MOED, 2005] and why we found less overlap between ISI and Google Scholar citations. On the contrary, in physics preprints and in computer science conference papers are the first choice for publication. Since in the social sciences Google Scholar gives more comprehensive citation results than the ISI [KOUSHA & THELWALL, TO APPEAR] and the ISI database has moderate coverage (below 40%) for research evaluation [MOED, 2005], it would be interesting to do a similar study for ISI-indexed journals in social sciences in order to discover the predominant style of scholarly communication in this subject area.

Conclusions

Our findings that the majority of Google Scholar unique citations (70%) were full-text scholarly sources is important evidence for the growth of OA publishing and self-archiving, although it clearly varies by discipline. Our results suggest that in physics and computer science the proportion of unique citations from Google Scholar is better *'quantitative'* value for measuring the citation impact of OA journals and articles (but see the limitations below). However, it is likely that a significant mass of non-refereed web documents which don't pass any '*qualitative*' process are indexed by Google Scholar although some may be postprints or preprints of subsequently accepted refereed articles. It is an unanswered question whether the inclusion of non-refereed citations would improve the value of citation scores. Would extra citations serve to better differentiate researchers' contributions to science or would they over-value low quality research?

For researchers using the citation tracking capability of Google Scholar for selecting a wider range of citations for their own work and non-evaluative purposes, our research indicates that a major benefit will be increased discovery of open access publishing. Hence this is evidence that Google Scholar provides a significant boost to the OA movement. However, the minimal amount of information known about Google Scholar's contents suggests caution for those seeking to use its citation data for research evaluation.

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Appendix
Open access ISI-indexed journals (2001) selected in four science disciplines

Biology	Chemistry
Acta Biochimica Polonica	*Acta Chimica Slovenica*
Acta Histochemica et Cytochemica,	*Analytical Sciences*
Biological Research	*Arkivoc*
BMC Cell Biology	*Boletin De La Sociedad Chilena De Quimica*
Brazilian Archives of Biology and Technology	*Bulletin of the Korean Chemical Society*
Brazilian Journal of Medical and Biological Research	*Ceramics-Silikaty*
Cell Research	*Croatica Chemica Acta*
Cell Structure and Function	*Journal of the Brazilian Chemical Society*
Cellular and Molecular Biology Letters	*Journal of the Serbian Chemical Society*
Journal of Biochemistry and Molecular Biology online	*Molecules, A Journal of Synthetic Chemistry*
Journal of Bioscience and bioengineering	
Journal of Biosciences	
Molecular Vision	
Revista de Biologia Tropical	

Physics	Computer
Acta Physica Polonica B	*IBM Journal of Research and Development*
Brazilian Journal of Physics	*IBM Systems Journal*
Chinese Journal of Physics	*Journal of Artificial Intelligence Research*
European Physical Journal A	*Journal of Machine Learning Research*
Journal of Nonlinear Mathematical Physics -ISI index	
Journal of the Society of Rheology Japan- ISI index	
M R S Internet Journal of Nitride Semiconductor Research	
New Journal of Physics	
Physical Review Special Topics-Accelerators and Beams	
Pramana Journal of Physics	
Progress of Theoretical Physics	