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How Much are LLMs Changing the Language of Academic Papers?

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Abstract

This study investigates the influence of Large Language Models (LLMs) on academic publishing with a term frequency analysis of 12 LLM-associated terms in six major scholarly databases (Scopus, WoS, PubMed, Dimensions, OpenAlex, and PMC) from 2015 to 2024. From the proportion of articles containing them, all 12 LLM-associated terms had small increases in 2023 and large increases in 2024. For example, in 2024, underscore[s/d/ing] appeared in 20% of PMC open access publications, a fivefold increase from 4% in 2022, suggesting that LLMs had influenced the language of at least 16% of PMC documents in 2024. LLM-friendly terms like delve[s/d/ing] and underscore[s/d/ing] seem to have grown partly at the expense of equivalent more traditionally academic terms like investigate[s/d/ing] and highlight[s/ed/ing]. There were disciplinary differences between the 27 Scopus broad subject categories, with underscore[s/d/ing] being more common in Environmental Science and "delve" more frequently used in Business and Humanities. There were also differences in the terms found in different parts of papers. For example, unveil[s/ed/ing] was used particularly more frequently in titles in 2024 than 2022 (0.26% vs. 0.04%), whilst underscore[s/d/ing] was more prominent in abstracts (2.5% vs. 0.21%) in Scopus. The increases may be due mainly to the use of LLMs for translation and proof reading, but imitation by researchers may result in LLM-associated terms becoming a more organic part of future academic writing, unless there is a reaction against them. Finally, since 70% of Scopus papers acknowledging ChatGPT did not use any of the 12 terms in their titles or abstracts, the influence of LLMs is probably much wider.

Introduction

Large Language Models (LLMs) like ChatGPT have the capability to help academic writing (Khalifa & Albadawy, 2024) such as editing and proofreading (Lechien et al., 2024), drafting abstracts (Gao et al., 2023; Hwang et al., 2024), creating literature reviews (Kacena et al., 2024; Margetts et al., 2024), statistical analyses (Huang et al., 2024), and even generating research hypotheses (Park et al., 2024). An Elsevier survey of researchers (n=2,284) found that about third (31%) used generative AI for research activities, and 93% found it helpful for writing and reviewing academic papers (Elsevier, 2024). A Nature survey of scientists (n=1,600) also found that almost half (47%) considered AI 'very useful' for academic tasks, with 55% believing it saves time and resources (Van Noorden & Perkel, 2023). A majority of surveyed urologists (58%, n=456) used ChatGPT for academic writing (Eppler et al., 2024) and 24% of authors in medical sciences (n=229) used LLMs for rephrasing, proofreading or translation (Salvagno et al., 2024). A survey of about 5,000

researchers found that 19% had used LLMs for the peer review process (Naddaf, 2025). Of 1,759 academic publications with ChatGPT acknowledgments, 80% mentioned language editing and proofreading or writing the manuscript and only 5% acknowledged for non-editorial research support (Kousha, 2024). However, a survey of 226 clinical researchers in 59 countries found that only 18.7% had used LLMs, mainly for grammar and formatting, and most did not acknowledge their use (Mishra et al., 2024).

Although several studies have attempted to estimate the prevalence of LLM use in academic publications, they have been limited in scope and methodology. An analysis of 2023 publications suggested that over 1% (about 60,000 papers) included LLM-associated terms (meticulously, innovatively, pivotal, intricate) (Gray, 2024). Another study found that 17.5% of Computer Science abstracts and 6.3% of Nature journal papers contained AI-modified content by using terms *realm, intricate, showcasing, pivotal* (Liang et al., 2024). In the biomedical sciences, the prevalence of LLMs terms (delves, showcasing, underscores) in PubMed abstracts rose to 10% by 2024 (Kobak et al., 2024). In dental research indexed by PubMed using terms delve, commendable, meticulous, innovative rose from 47.1 to 224.2 papers per 10,000 (Uribe & Maldupa, 2024). Using AI detection tools, a study estimated that 10% of 45,000 papers published between December 2022 and February 2023 were likely written with the help of ChatGPT (Picazo-Sanchez & Ortiz-Martin,2024). Despite these, there is a lack of subject-wide evidence from 2024, a year when a substantial fraction of authors could potentially have used ChatGPT (released November 2022) for their initial drafts, a lack of cross-database validation studies and a lack of comparisons of term frequencies in different text parts.

Research questions

This research expands on previous studies by using updated data to the end of 2024 (from 2015) and analysing the broader use of 12 LLM-associated terms across six major scholarly databases (Scopus, WoS, PubMed, Dimensions, OpenAlex, and PMC). It compares trends in the use of these terms between subjects and with other common research terms to assess changes before and after the introduction of LLMs like ChatGPT. The following research questions guide this study:

1. How has the prevalence and proportion of LLM-associated terms in academic publications changed from 2015 to 2024, and does the answer vary between major scholarly databases?
2. Are there disciplinary differences in the use of LLM-associated terms?
3. Are any LLM-associated terms particularly common in article titles or abstracts?

Methods

In this study, we investigated the potential applications of LLMs in academic writing before and after ChatGPT's November 2022 release using a range of major bibliometric databases. We searched for terms associated with LLMs in previous studies or identified through our initial tests. For the latter, we extended the list of LLM-associated terms by analysing the frequency of terms in titles and abstracts of Scopus articles in Environmental Studies. Although differences between fields are expected, Environmental Studies was selected because it is large and the identified terms were especially frequent within it.. For this we first searched for terms previously identified in related studies in titles and abstracts of Scopus articles in Environmental Studies and then identified new terms that (a) frequently co-occurred with the existing terms ($p < 0.01$, χ^2 test) and (b) had a sudden increase in frequency in 2024. We selected 12 terms to keep the analysis manageable and consistent across databases and subjects.

Table 1. lists the final terms selected for analysis in this study, along with their related sources and the queries used within the databases. Although we have no direct cause-and-effect evidence for these terms originating ever from LLMs, it seems reasonable to hypothesize that increases in their use are due to LLMs since previous research has made this assumption and the terms are general, with no obvious other source (unlike "Covid-19" or "LLM", for example).

Table 1. Identified terms potentially associated with LLM in academic publications.

Queries for terms possibly associated with LLMs	*Related source*
underscore OR underscores OR underscored OR underscoring	Kobak et al., 2024; Uribe & Maldupa, 2024
delve OR delves OR delved OR delving	Kobak et al., 2024; Uribe & Maldupa, 2024
showcasing OR showcase OR showcased OR showcases	Kobak et al., 2024; Liang et al., 2024; Uribe & Maldupa, 2024
unveil OR unveils OR unveiled OR unveiling	Uribe & Maldupa, 2024
intricate OR intricacies OR intricately	Gray, 2024; Liang et al., 2024; Uribe & Maldupa, 2024
meticulous OR meticulously	Gray, 2024; Uribe & Maldupa, 2024
pivotal	Gray, 2024; Liang et al., 2024
heighten OR heightened OR heightens OR heightening	Authors' analysis
nuanced OR nuance OR nuances	Authors' analysis
bolster OR bolstering OR bolsters OR bolstered	Authors' analysis
foster OR fostering OR fosters OR fostered	Authors' analysis
interplay OR interplays OR interplayed OR interplaying	Authors' analysis

The terms identified were searched for separately in titles, abstracts, and keywords in Scopus, WoS, and PubMed, and with unrestricted searches in three hybrid platforms that index some full text documents and some title/abstract metadata: OpenAlex, Dimensions, and PMC. The results were limited to articles, reviews, and proceedings papers published between 2015 and 2024 to analyse term usage over a decade, to guard against changes since 2022 being part of a longer-term trend unrelated to LLMs. Since the number of publications increased over time (e.g., fewer publications in 2015 than in 2024), the results were divided by the total number of publications indexed annually in each database. This approach allowed a proportional analysis of term usage, improving on previous studies that reported only raw frequency counts. All searches were conducted on 20 December 2024 to minimise the potential impact of daily increases in publications.

Results

Proportion of publications with LLM-associated terms

There were small increases in the percentage of documents containing the 12 terms in all databases in 2023 and much larger increases in nearly all cases 2024 (Figure 1). OpenAlex provides a slight anomaly, with increases in 2023 but not 2024. This might be due to OpenAlex recording the first date that it found a publication (including a preprint) rather than its formal publication date, so it may tend to be a year ahead of the other databases. In terms of other database differences, title/abstract/keyword search results for WoS and Scopus are similar but not identical, and, unsurprisingly, the highest results occur for the databases that include some full texts (PMC and Dimensions). This tends to confirm that LLMs are not only used to produce or polish article abstracts. OpenAlex is also an anomaly here, but this suggests that it indexes a low percentage of full text documents.

In 2024, *underscore[s/d/ing]* was the term most frequently used: about 20% of PMC open access publications followed by *pivotal* (15%) and a similar pattern was observed in Dimensions publications (11% and 8% respectively). Overall, the results indicate a clear and substantial overall increase in the proportion of academic publications using potentially LLM-related terms across multiple databases from 2022 onward. Figure A1 in the appendix shows the number of academic publications with LLM-associated terms across databases and years (2015-2024).

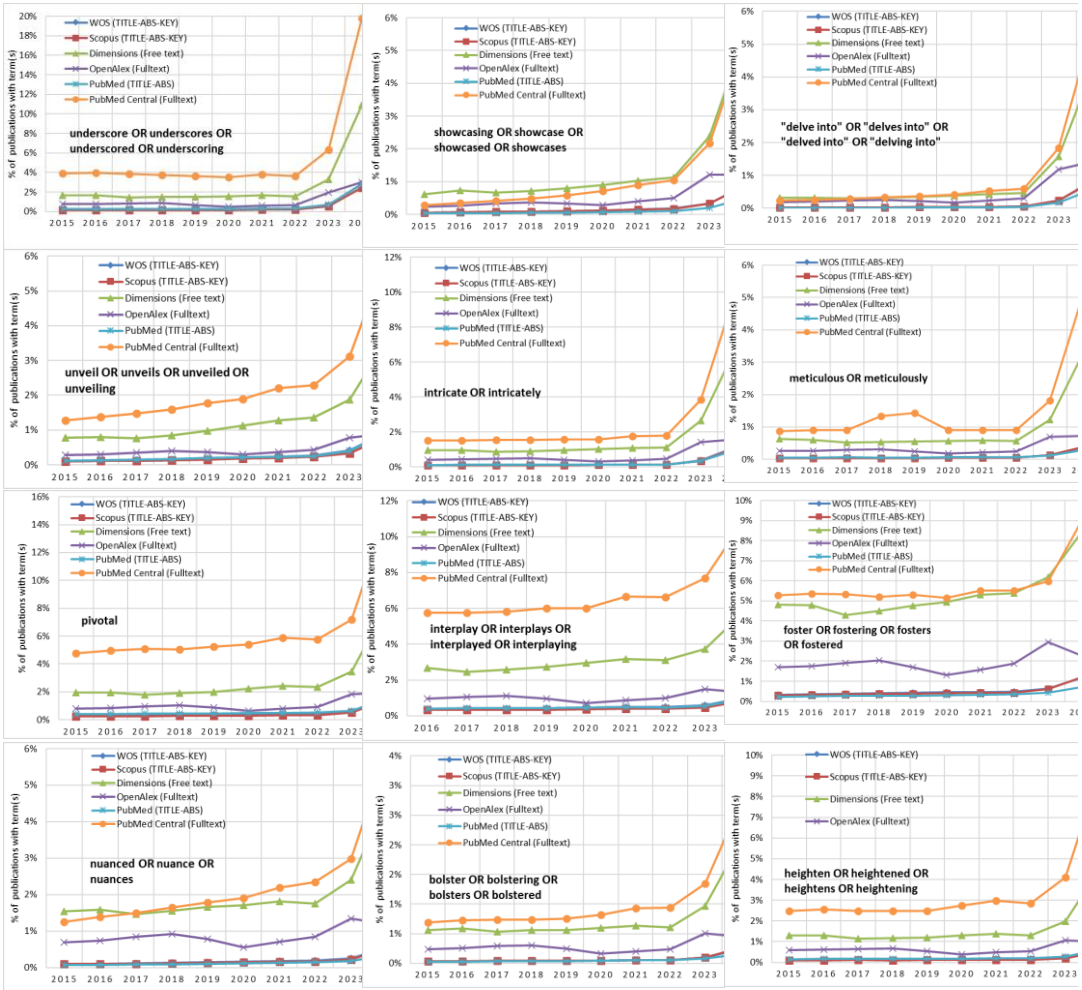

Figure 1. Percentage of 12 LLM-associated terms in academic publications in six databases.

Growth in LLM-associated terms in academic publications (2022-2024)

The terms *delve* and *underscore* had the highest growth between 2022 and 2024, with increases more than 1500% (i.e., a 15-fold increase) and 1000% in Scopus (10-fold) and WoS, respectively (Figure 2). *Intricate* and *meticulous* also experienced significant growth: above 400% in several databases. However, the terms *interplay* and *foster* had much lower increases: below 200% in several platforms. This great variability in increases may reflect a range of factors, such as their initial rarity, whether they are similar to more academic terms that they have replaced, and how often they occur in non-academic texts (where LLMs presumably learn how to use them).

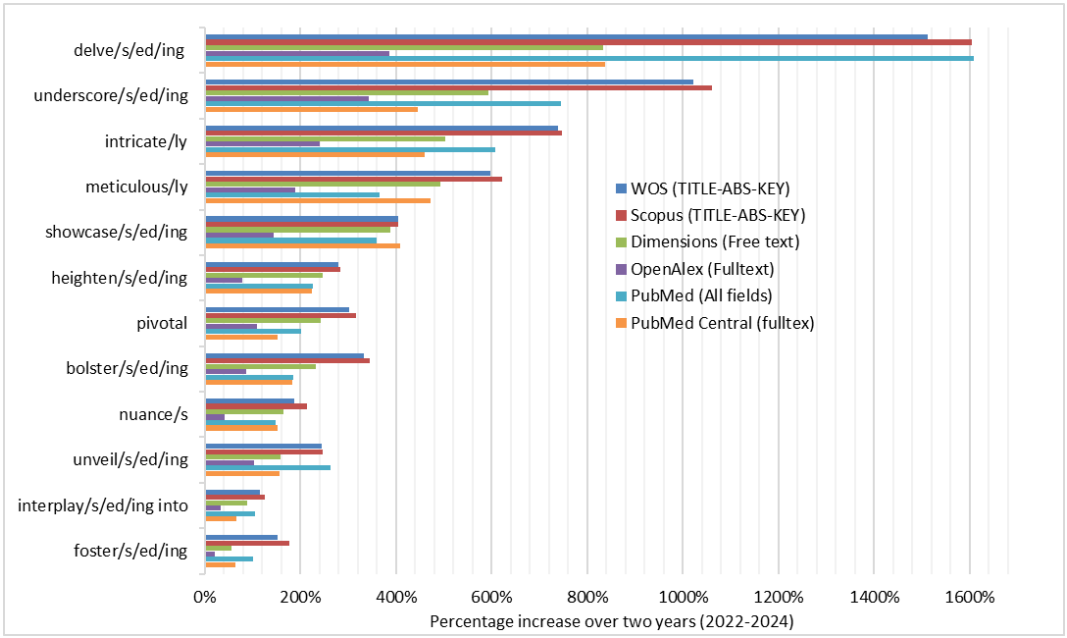

Figure 2. Percentage increase from 2022 to 2024 in the use of LLM-related terms in academic publications.

Disciplinary analysis

The percentage of LLM-associated terms in academic publications (title, abstract, or keywords) differed between Scopus subject areas in both 2022 and 2024. The term *underscore[s/d/ing]* increased dramatically in Environmental Science (0.26% to 3.84%), Business, Management, and Accounting (0.38% to 3.54%), and Economics, Econometrics, and Finance (0.35% to 3.57%) (Figure 4). Similarly, *delve[s/d/ing]* increased sharply in Business, Management, and Accounting (0.16% to 1.67%), Arts and Humanities (0.37% to 1.67%), and Economics, Econometrics, and Finance (0.12% to 1.51%) (Figures, A2 and A3, in the appendix). Hence, there seems to be some disciplinary difference in appearance of the selected terms across subjects, although this needs further investigation.

Table 2 shows the Pearson correlations between the percentage of terms in Scopus papers between 2022 and 2024 within 27 subject areas, indicating differences in their increases between disciplines. Foster[s/d/ing] (0.971), nuanced (0.966), and unveil[s/ed/ing] (0.923) have the highest correlations, suggesting a consistent increase across most subject areas and widespread usage in the titles and abstracts of academic publications. In contrast, meticulous[ly] (0.204), underscore[s/d/ing] (0.655), and bolster[s/ed/ing] (0.64) have lower correlations, indicating greater variation between subject areas, suggesting their growth may be more field-specific and could be related to research trends or discipline-specific terminology which needs further investigation.

Table 2. Pearson correlations between the percentage of LLM-associated terms in Scopus papers in 2022 against 2024 by Scopus subject. All correlations were statistically significant at the p < 0.01 level (n=27 subjects).

LLM-associated terms	*Correlation*
delve[s/d/ing]	0.807
underscore[s/d/ing]	0.655
showcase[s/d/ing]	0.744
unveil[s/ed/ing]	0.923
intricate[s/d/ing]	0.771
meticulous[ly]	0.204
heighten[s/ed/ing]	0.898
pivotal	0.677
nuance[s/d]	0.966
bolster[s/ed/ing]	0.64
foster[s/d/ing]	0.971
interplay[s/ed/ing]	0.879

The scatter plots in Figures 3 and 4 reflect a strong positive correlation between the percentage of delve[s/d/ing] and underscore[s/d/ing] in Scopus papers from 2022 to 2024 across the 27 Scopus subjects. Figure 3 shows that delve[s/d/ing] has increased consistently across most disciplines, with the highest percentages in arts & humanities, social sciences, and business. These fields have had a steady upward trend, suggesting that delve[s/d/ing] has frequently been used in abstracts or titles or recent research. In contrast, in most medical fields delve[s/d/ing] had a lower percentage increase, indicating that the term remains less commonly used in their published research.

Figure 4 also shows similar trends for underscore[s/d/ing], indicating that psychology, social sciences, environmental science, business, and economics have had the largest increases. In contrast, mathematics, physics, and dentistry have had lower percentages in using these terms. Medical subjects, such as neuroscience and medicine also showed increases, reflecting a growing use of underscore[s/d/ing] in the abstracts of Scopus papers. (see also Figure 6 below).

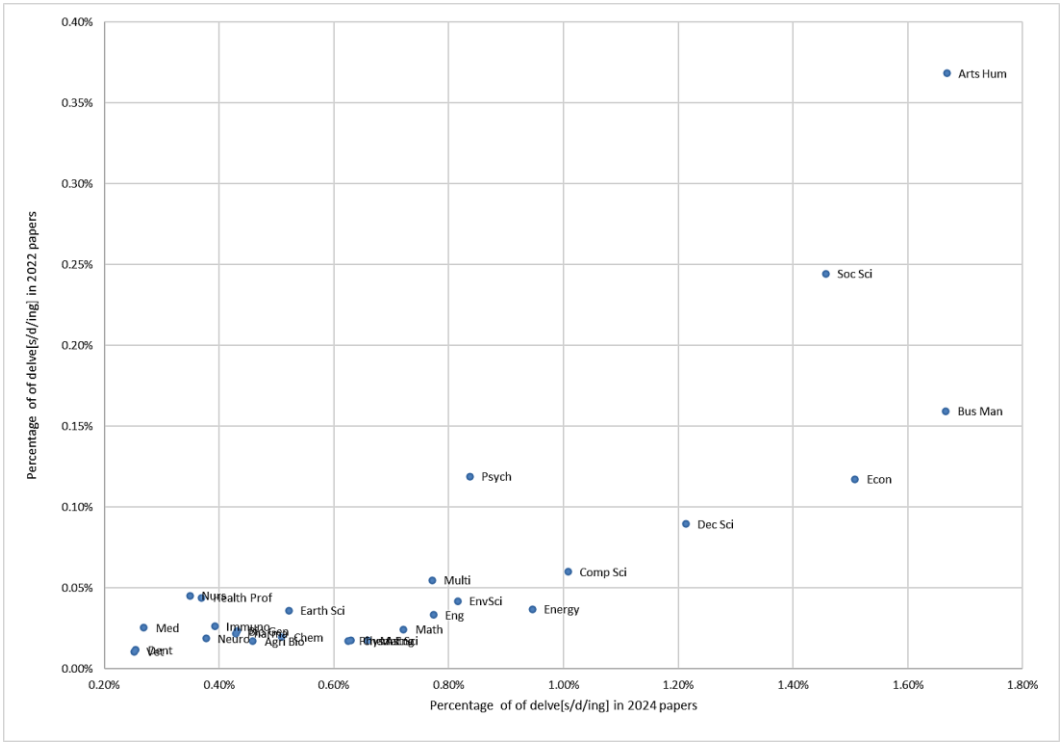

Figure 3. Scatter plot of the percentage of *delve[s/d/ing]* in Scopus papers (2022 vs 2024) across 27 subjects.

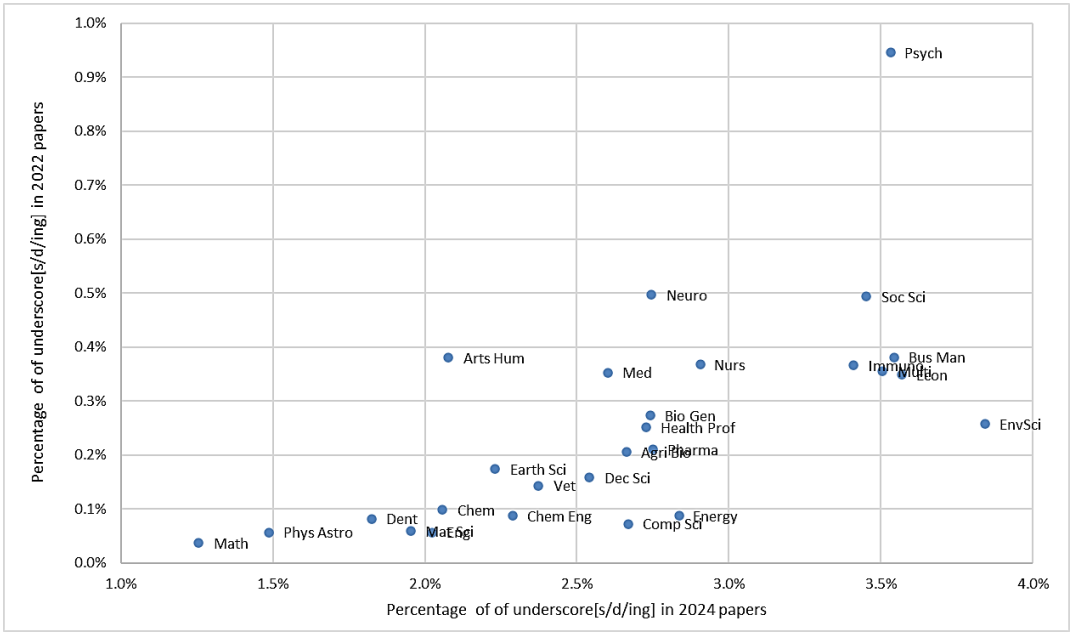

Figure 4. Scatter plot of the percentage of *underscore[s/d/ing]* in Scopus papers (2022 vs 2024) across 27 subjects.

Terms in titles and abstracts of papers

The term "unveil" was particularly common in titles in 2024 (0.26%) compared to 2022 (0.04%) and seems to be by far the most title-friendly LLM-associated term of the 12 investigated (Figure 5). In contrast, for abstracts, the term "underscore" had the biggest increase, from 0.21% in 2022 to 2.53% in 2024, and all the other terms had substantial increases (Figure 6).

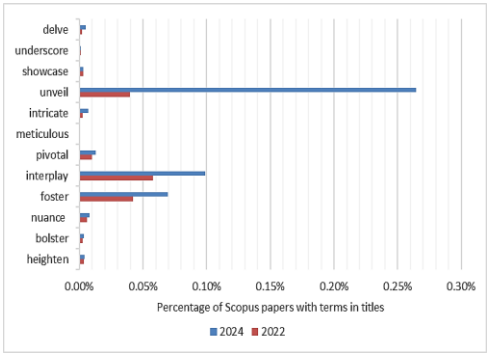

Figure 5. Percentage of Scopus publications with titles containing the selected terms (2024-2022).

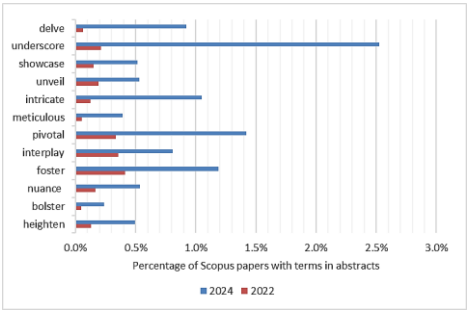

Figure 6. Percentage of Scopus publications with abstracts containing the selected terms (2024-2022).

Discussion

The results are limited by the set of 12 terms used and the six databases, and we may have overlooked terms that are used by LLMs other than ChatGPT. The results may also change in the future as LLMs evolve and if, for example, DeepSeek largely replaces existing LLMs. Our analysis is based on English-language terms and metadata (e.g., titles and abstracts) which may introduce bias. For example, non-English articles indexed with translated English abstracts could contain LLM-associated terms even if the original manuscript does not. Moreover, non-native English-speaking authors may often use LLMs for proofreading and translation to improve clarity which could influence LLM term counts.

Unlike studies that use AI detectors to identify generated text (e.g., Picazo-Sanchez & Ortiz-Martin, 2024), our approach looked at the percentage of specific vocabulary changes in publications across databases and disciplines. Although AI detectors can be used in small-scale studies, they are not practical for large-scale analyses, such as processing the abstracts of published papers across years and disciplines. Moreover, uploading academic full texts (e.g., from PMC) without authors' consent may raise ethical concerns.

Moreover, this study did not assess the average use of these terms in the full texts of publications which could provide different results compared to titles and abstracts,

where LLM-associated terms are more likely to appear only once. Hence, future studies should investigate this using large-scale data from full-text papers.

Comparing the increase of LLM with common research terms

A follow-up analysis conducted on data collected on 28 January 2025 confirmed that the use of LLM-associated terms continues to increase in frequency in the title, abstract or keywords of Scopus papers. In contrast the frequency of an ad-hoc selection of more traditional academic terms with similar meanings, used here as control terms, is relatively stable (Table 3). This supports, but does not prove, the hypothesis that LLMs are the cause of the differences rather than changes in what scientists have written about, or lengthening abstracts (which would make all terms more common).

Table 3. Percentage increase in common vs. LLM-associated terms in Scopus papers (2022–2024).

Common term	2022 (%)	2024 (%)	**% Increase**	**LLM term**	2022 (%)	2024 (%)	**% Increase (2022-2024)**
investigate	17.83	19.41	**8.90%**	delve	0.07	1.05	**1360%**
highlight	5.08	9.43	**85.68%**	underscore	0.25	2.87	**1062%**
demonstrate	14.07	20.35	**44.72%**	showcase	0.20	0.99	**395%**
reveal	12.03	16.02	**33.25%**	unveil	0.26	0.88	**235%**
complex	10.02	11.78	**17.63%**	intricate	0.14	1.20	**727%**
precise	1.74	2.93	**67.94%**	meticulous	0.06	0.45	**611%**
critical	6.45	7.99	**23.92%**	pivotal	0.40	1.62	**308%**
enhance	9.56	18.76	**96.25%**	heighten	0.15	0.57	**273%**
detail	4.16	4.37	**4.94%**	nuanced	0.20	0.61	**210%**
strengthen	1.48	1.65	**11.42%**	bolster	0.06	0.27	**361%**
promote	5.87	6.99	**19.17%**	foster	0.50	1.40	**177%**
interaction	8.25	9.06	**9.89%**	interplay	0.45	0.99	**119%**

Are academics reviewing LLM-generated texts?

The extent to which LLMs like ChatGPT are used in academic writing (e.g., minor grammatical edits, spell checking, or fully drafting sections or abstracts) requires further qualitative and quantitative investigation. However, out of 1,540 academic papers with ChatGPT acknowledgments related to manuscript editing and production (see data from Kousha, 2024), about a third (31%) included one or more of the 12 LLM-associated terms in their titles or abstracts (e.g., underscore[s/d/ing] (7.3%), pivotal (4.2%), and intricate[s/d/ing] (3.7%). Since 69% did not include any of these terms, the highest of the results above (a 16% increase for underscore)

probably underestimate the prevalence of LLM support for academic writing: the real figure may be at least triple (1/0.31=3.23) the maximum reported here. If LLMs are widely used for editing, common phrases like “underscore” or “delve” may become even more popular in academic writing in future.

Conclusions

In answer to the first research question, the findings show a clear increase in the prevalence and proportion of LLM-related terms after ChatGPT's release in late 2022. For instance, the terms delve[s/d/ing] and underscore[s/d/ing] had significant growth across different scholarly databases between 2022 and 2024 (1360% and 1062% in Scopus, respectively). In contrast, other common research terms such as investigate[s/d/ing] and highlight[s/ed/ing] had only slight increase (only 9% and 86%) over the same period. The term "underscore" appeared in 20% of PMC publications and 11% of Dimensions publications, indicating a considerable shift using it in academic writing. The 16% increase for underscore[s/d/ing] suggests that at least 16% of academic publications published in 2024 had their language influenced by LLMs, and the above discussion suggests that the overall figure for LLM influence is probably at least triple this (i.e., close to half).

In answer to the second research question, there were noticeable disciplinary differences in how LLM-related terms were used. For example, underscore[s/d/ing] was particularly prominent in Environmental Science (0.26% to 3.84%) and Business (0.38% to 3.54%).

In answer to the third research question, the use of LLM-related terms varied substantially between titles and abstracts. For instance, unveil[s/ed/ing] was more common in titles (0.04% to 0.26%), while underscore[s/d/ing] appeared more often in abstracts (0.21% to 2.53%) in 2022 and 2024 respectively.

Although this study provides new evidence that LLMs like ChatGPT may have influenced academic writing through the analysis of updated data, a broader range of terms, and multiple scholarly databases, further research is needed to understand how LLMs are shaping academic publishing across specific subjects, considering their relatively recent introduction. Different LLMs (e.g., ChatGPT, Gemini, and DeepSeek) may use unique terms when generating or editing academic texts. Hence, future research could investigate differences between LLMs in their influence on academic writing.

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Appendix

The Number of academic publications with LLM-associated terms

All 12 potentially LLM-associated terms increased significantly in academic publications from 2023, after ChatGPT was released in November 2022 (Figure 8). For example, in Dimensions, mentions of *delve* related terms ("delves," "delving," "delved,") increased from 30,329 in 2022 to 268,483 in 2024 (785% increase). Similarly, *underscore* related terms increased by 557%, and *showcase* related terms by 364%. In Scopus, mentions of *delve* in titles, abstracts, or keywords increased by 1,582% (from 1,852 in 2022 to 31,149 in 2024) with similar increases found for *underscore* (1,046%), *showcase* (397%), and *unveil* related terms (243%). In PubMed, *delve* and *underscore* increased by 1,491% and 688%, respectively. These trends suggest that LLMs like ChatGPT are increasingly being used in academic publications after about two years of its release.

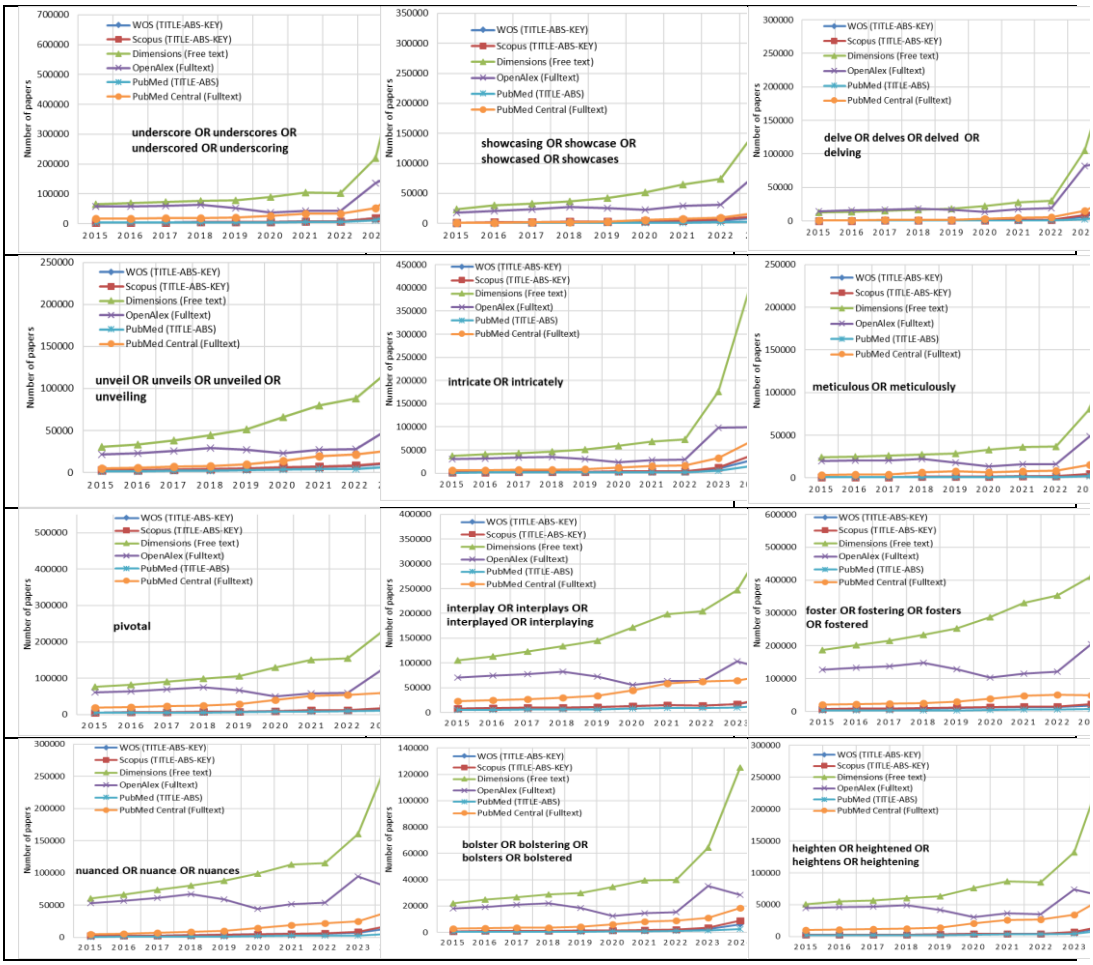

Figure A1. Number of academic publications (2015–2024) containing 12 potentially LLM-related terms across bibliographic and open-access databases.

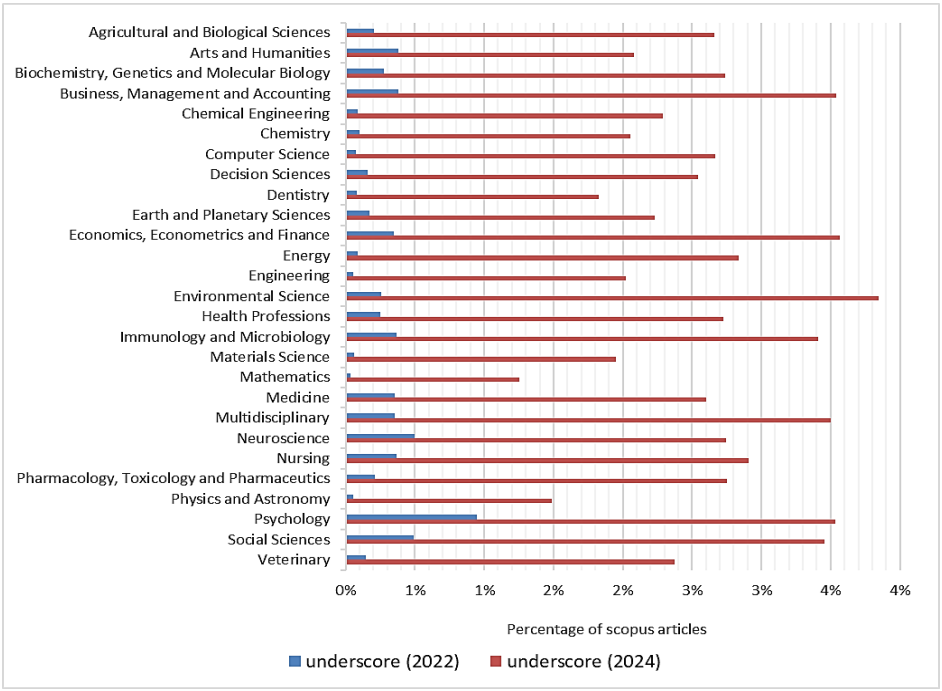

Figure A2. Percentage of Scopus papers with *underscore[s/d/ing]* in their title, abstract or keywords in 27 subjects (2022-2024).

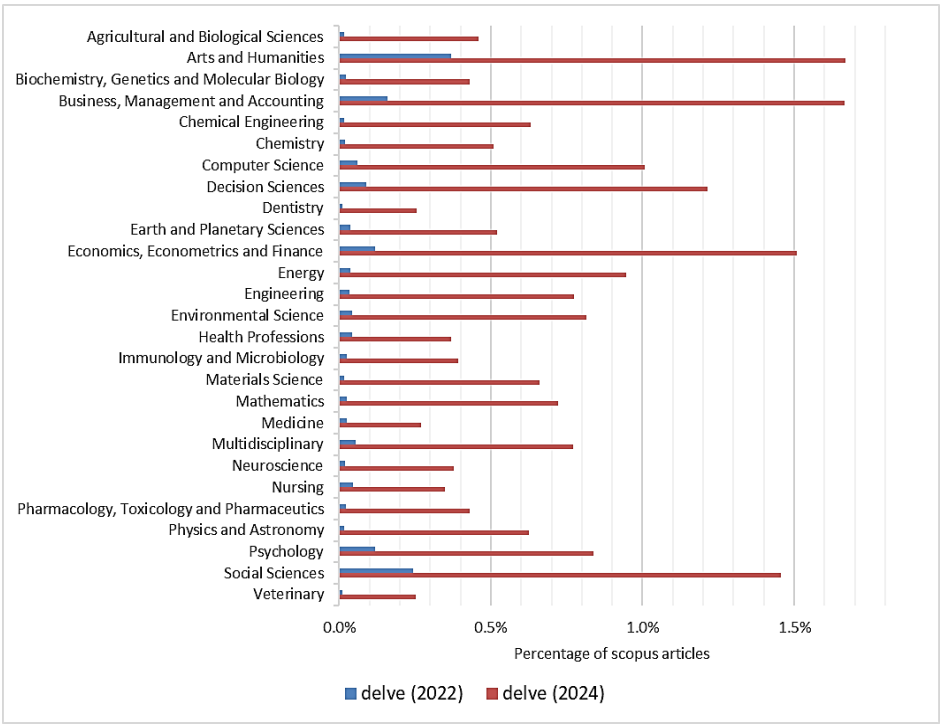

Figure A3. Percentage of Scopus papers with delve[s/d/ing] in their title, abstract or keywords in 27 subjects (2022-2024).